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Determinants of Performance of Irrigation Projects in Developing Countries

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ABSTRACT

Irrigation development in developing countries is very expensive and most irrigation development projects experience large cost-overruns. In addition, many projects are not as productive as planned. This report provides some insight into the key factors which cause cost escalation and performance degradation, and describe policies which may help to remedy these problems.

Keywords: Irrigation, developing countries, cost-effectiveness, simulation, modeling.

CONTENTS

SUMMARY

As the population of the world grows, the demand for food increases. In the developing regions of Asia, Africa, and Latin America, where population growth is fastest, the gap between food supply and food demand is expanding rapidly. This food deficit must be made up by increasing domestic food production or by importing food. Yet many of the world's poorest countries do not have either enough capital to undertake development of domestic agriculture or sufficient foreign exchange to import the needed food. It is, therefore, essential that each investment must be as cost-effective as possible.

Irrigation is a major component of investment in the improvement of food production especially in countries, particularly in Asia, where there is little additional land to cultivate. Irrigation development is noted for being relatively costly and sometimes cost-ineffective. If the cost-effectiveness of irrigation projects could be improved, developing countries would benefit from more economical use of investment funds and increased agricultural production.

Four factors are very important in determining cost-effectiveness and can be influenced by policy choices. These four factors are:

- the physical environment of the project;
- the planning, design, and implementation process;
- the operation and maintenance of the project; and
- farm socioeconomics.

Each of these factors limits the potential cost-effectiveness that a particular irrigation development project may achieve. The physical environment limits the overall productive capacity of the area served; the planning, design, and implementation process shapes the quality of the physical structures, their performance, the manageability of the system, and bulk of the costs; operation and maintenance can further constrain or reduce the adequacy and reliability of the system; and farm socioeconomics determine the farmer's ability and incentives to utilize the available resources productively.

This study looks closely at the interactions of the key factors and how they act to determine cost-effectiveness. A system dynamics computer simulation model is used to explain how cost-effectiveness is determined, to simulate the behavior of a hypothetical irrigation project, and to test the impact of various policies on the hypothetical project.

Four important conclusions came out of the analysis:

1) Irrigation projects are complex systems comprising a variety of physical, social, and economic factors which act in concert to determine performance. Failure to recognize irrigation projects as complicated physical and social systems may be the major cause of poor cost-effectiveness.

2) The project design and information collection period is an especially sensitive time for determining the cost-effectiveness of a project.

If appropriate effort is made during this time to understand the project environment and produce a high-quality design, success will be much more likely.

3) The inclusion of certain project elements such as extension programs, water delivery regulations, and thorough information collection at the planning stage, while relatively inexpensive components in comparison with construction costs, may be essential in determining project success.

4) The most cost-effective program for maintaining the physical structures may be one which does not support maximum system performance, but only minimum system operation for the length of a reasonable payback period.

BACKGROUND

The Food Problem

The population of the world is growing at a rapid pace. In 1930, the total world population was about 2 billion people. It took only 30 years to add another billion and just 15 more years to add yet another billion. By the year 2000, the world will be inhabited by an estimated 6 billion people (20). This burgeoning population poses a great many problems. Among these, food production is an issue which demands immediate attention.

As population and affluence increase so does the demand for food. Food consumption has been growing at a rate of about 2.5 percent per year, approximately 80 percent of which can be attributed to population growth in the less developed countries. The remaining 20 percent can be accounted for by the increasing wealth of the developed nations. Food production is also growing, but it is just keeping ahead of demand (5).

Prior to World War II, the developing regions of Latin America, Africa, and Asia were net food exporters. By 1950, however, these developing regions were no longer producing a surplus but instead were importing about 5 million tons of food per year. In 1960 the food deficit for these regions totaled 19 million tons; in 1973, 47 million tons; and in 1976, 60 million tons per year. Estimates put the food deficit between 100 and 200 million tons per year by 1985 (20). A food deficit may not necessarily be a problem as long as a country has the ability to pay for the food it imports. Many developing countries, however, do not have sufficient foreign exchange to supplement their own food production, and as a result millions of people living in these countries do not have an adequate amount of protein or calories in their diet. The Food and Agriculture Organization of the United Nations estimated in 1970 that 430 million people were malnourished (14).

The long-term solution to this problem is to stabilize the world's population at a sustainable level, as ultimately, some level of food production will be reached at which increases in production will become prohibitively expensive or difficult to achieve. Sriplung and Heady (15) suggest that if food availability can keep ahead of food demand for another 30 to 50 years, it may be possible to implement the necessary population control policies. Investment in agricultural development may thus buy the time needed to achieve a sustainable balance between population and food production.

Sriplung and Heady (15) point out five means of increasing food availability:

- increasing per-unit yields through improved technologies,
- intensifying the use of land already under production,
- bringing more land into agricultural production,
- reducing spoilage and consumption by pests, and
- diverting grain from livestock to humans for direct consumption.

Each of the sources except for the last entails a significant expense which developing nations may have difficulty paying.

The Cost of Meeting Food Demand

Thirty-six low-income countries have been identified as likely to be food-deficient by the year 1990. To keep pace with growing food demand from population growth, income growth, and nutritional improvement, food supply in these countries will have to increase at a rate of 3.5-4.5 percent per year (13).

To attain these high rates of growth, the 36 nations would have to make a tremendous financial investment of nearly $100 billion dollars by 1990 (13). Table 1 shows the breakdown of investment categories and costs as estimated by Oram. The most noticeable category is that of water resource development, which accounts for over half of the total investment needs.

Water resource development (irrigation and drainage) accounts for a large proportion of the total investment for three principal reasons. First, irrigation is essential in many areas for increasing yields. Irrigation can eliminate plant stress during periods of water shortage, thus producing higher and more stable yields. Second, irrigation can supply water during times of the year when crops are not normally grown, allowing two or three crops to be grown on the same land during the year. Third, irrigation can support crop production in arid areas previously too dry to enable any crop growth. For land-constrained countries, irrigation may be the only way to increase food supply. Thus, irrigation development accounts for the large share of the estimated total investment which water resource development commands.

Table 1--Capital costs of producing additional food crops in 36 low-income countries by 1990 (1975 dollars)

Investment categories	Capital costs
	Billion dollars
Water resource development	52.0
Land settlement	9.9
Road improvements	7.2
Rural electrification	6.0
Disease eradication	1.6
Fertilizer use (manufacturing)	9.1
Seed industries	.3
Mechanization	4.2
Animal draft	.9
Storage and drying	4.5
Research	1.6
Extension	1.4
Cumulative total	98.7
Annual average	6.6

Source: (13), p.15.

Some countries may be able to expand production by increasing the land base under production. However, land expansion presents itself as an alternative only in those countries that have a considerable amount of land still uncultivated. Therefore, the only alternative for the land-constrained countries is to increase the production per unit of land by increasing the number of seasons (multiple cropping) and by increasing yields. Asia is the region of primary concern in this regard. Table 2 shows that the land base for agricultural production increased by only 5 percent in Asia between 1961-65 and 1977. Table 3 shows that the amount of land per person is smaller in Asia than in any other region of the world.

Asia historically has been able to intensify production through irrigation, thereby using a greater proportion of the land's potential for agricultural production. Asia has much more land under irrigation than the other regions of the world, as illustrated in table 4.

Table 5 shows that Asia will continue to rely upon irrigation for almost three-fourths of future increases in food production.

The costs of these increases in food production are substantial and it will be difficult for capital-deficient developing countries to make the necessary investments to keep up with food demand. Complicating this issue is the fact that agricultural development investments are only one component of development programs in these countries. Investments in industry, transportation, education, health, and energy, among others, also need to be made. Often development expenditures for agriculture only amount to 15-25 percent of the total development budget in developing countries, even though the agricultural sector in these countries typically employs 70-80 percent of the population and generates 40-50 percent of the total gross domestic product (6).

Table 2--Annual average increase in areas under arable and permanent crops during 1961-65 to 1977

Region	Area in arable and permanent crops: 1961-65	Area in arable and permanent crops: 1977	Area in arable and permanent crops: Increase	Increase in population during 1970-78
	Million hectares		Percent	Percent
Africa	188	208	10.6	24
Asia	436	458	5.0	18
South America	82	108	31.7	24
All developing countries	722	791	9.6	19
All developed countries	657	671	2.1	7
World	1,379	1,462	6.0	16

Source: (2), p. 26.

Table 3--Arable land per person

Region	Arable land per capita, agricultural population	Arable land per capita, total population
	Hectare/person	
Africa	0.72	0.48
Asia	.32	.19
South America	1.40	.46
All developing countries	.42	.26
All developed countries	4.39	.59

Source: (2), p. 27.

Table 4--Increase in areas under irrigation during 1961-65 (annual average) to 1977

Region	1961-65	1977	Percentage increase
	Million hectares		Percent
Africa	5.8	7.8	13.4
Asia	100.0	128.8	28.8
South America	4.9	6.5	32.6
All developing countries	110.0	144.9	31.7
All developed countries	39.0	52.9	35.6
World	149.0	198.0	32.9

Source: (2), p.28.

Table 5--Projected increases in food production from irrigated and rainfed land in Asia

Item	Increase, 1975-90	Percentage of total increase
	1,000 tons	Percent
Irrigated areas:		
New areas	48,785	36
Improved areas	25,416	19
1975 existing area	25,649	19
Subtotal	99,850	73
Rainfed areas:		
Rainfed expansion	15,389	11
1975 existing area	21,681	16
Subtotal	37,070	27
Total increase	136,920	100
Total 1974-76 food production	187,020	NA
Total 1990 food production	323,940	NA

NA = not applicable.

Source: (8), p. 6.

To meet the projected demand for food, the developing nations of Asia will have to invest heavily and effectively in agriculture. In 1978, the Trilateral Commission recommended that the rice production in the developing countries of Asia be doubled in the period 1978-93. This would increase the irrigated area in those countries from 32.7 million hectares to 86.8 million hectares at an estimated cost of $52.6 billion (1975 dollars) or $3.5 billion per year (7). The International Food Policy Research Institute (13) came up with very similar estimates ($52 billion or $3.5 billion per year at 1975 prices) projecting a net increase in irrigated area of 2.3 percent annually. This level of investment is significant for any country, but particularly so for countries where per capita incomes may be $200 or less per year (6). In poor countries where capital is scarce and needs are great, it is likely that all agricultural investment requirements will not be fully met. It is of paramount concern then, that those investments which are made must be cost-effective.

The Cost of Irrigation

Major irrigation projects are significant investments, when considered on either a per-unit cost or total cost basis. Table 6 shows that the average cost per hectare for a new irrigation system ranges from a low of $1,900 to a

Table 6--Average capital investment for new irrigation system and for improvements on existing irrigation system

Region	New irrigation	Major improvements	Minor improvemnts
		Dollars/hectare	
Africa (excluding NE Africa)			
North of Sahara	2,500	900	400
South of Sahara	2,800	900	400
Latin America			
Central America & Mexico	2,400	800	300
Caribbean	2,400	800	300
South America	1,900	600	200
Near East			
Northeast Africa	3,100	900	500
Middle East	2,600	900	500
Asia			
South Asia	2,900	700	300
Southeast & Far East	3,000	700	300

Source: (13), p.58.

high of $3,100. Improving or rehabilitating an existing irrigation system is a much less costly endeavor, ranging from $200 per hectare to $900 per hectare. However, investments in both new and rehabilitative irrigation projects are well known for their tendency to be more costly and less effective than originally planned.

Table 7 illustrates how drastically actual costs can deviate from pre-project estimates. Cost data on 18 irrigation projects were collected from reports written during construction or after the projects were completed. A comparison of target and actual costs reveals that these projects typically experience significant cost overruns and may produce fewer benefits than expected. On a per-hectare basis, the average cost overrun was 152.4 percent, with a range of 8.3 percent to 536.5 percent. On a total cost basis, the average cost overrun was 92.2 percent, the lowest overrun a negative 33.3 percent and the highest a positive 175.8 percent. The differences in the figures from the two types of overruns can be explained by looking at the target and actual area developed. Take for example project 16. The cost to develop this project was actually less than expected. However, this was accomplished by a significant reduction in the area developed, as the area irrigated amounted to only 38 percent of the target. The data from project 1 show a similar occurrence. The cost per hectare for this project is the highest in the sample, and the final cost almost 5 times the original

Table 7—Performance data for 18 irrigation projects in developing countries

Region/type	Project number	Area		Cost		Time overrun	Total cost	
		Target	Actual	Target	Actual		Target	Actual
		1,000 hectares		Dollars/hectare		Years	Million dollars	
Asia:								
New irrigation projects	1	100	34	1,270	6,205	8	127	211
	2	16.2	17.8	1,012	2,515	3	16.4	44.7
	3	102	102	815	883	3	83.1	90.1
	4	11.56	4.52	562	3,577	3	6.5	16.2
	5	77	65	812	1,968	9	62.5	127.9
	6	19.7	19.7	939	1,188	3	18.5	23.4
Subtotal		326.46	243.02	1/962	1/2,203	--	314	513.3
Rehabilitated irrigation projects	7	186	200	199	390	NA	37	77.9
	8	200	177.8	146	366	NA	29.1	65.1
	9	229	184	102	254	NA	23.4	46.8
	10	20.1	16.1	NA	518	8	NA	8.35
	11	29.6	28.4	277	625	1	8.2	17.8
	12	39.8	38.4	239	520	2	9.5	20.0
	13	4.3	4.4	1,159	2,518	5	5.1	11.08
Subtotal		708.8	649.1	1/2/163	1/2/379	—	112.3	238.68
Other areas:								
New irrigation projects--								
Latin America	14	203	202.6	468	1,293	11	95	262
Africa	15	126	126	786	3,175	NA	99	400
Africa	16	488	184	362	640	NA	176.5	117.7
Subtotal		817	512.6	453	1,521	--	370.5	779.7
Rehabilitated								
Latin America	17	10	7.88	780	1,923	1	7.8	15
Latin America	18	35	35	1,646	2,074	1	57.6	72.6
Subtotal		45	42.88	1,453	2,043	--	65.4	87.6
Total new irrigation projects		1143.46	755.62	599	1,711	--	684.5	1,293
Total rehabilitated		753.7	691.98	242	483	—	177.7	326.28
Total		1897.16	1447.6	424	1,070	--	796.8	531.68

NA = Not available.

1/ Weighted average.
2/ Project #10 not included.

-- = Not applicable.

estimate. Yet, the total cost for the project was just 66 percent higher than expected. Again, we see that the project area developed was only one-third of that planned.

In its 1982 project audit, the World Bank (19) calculated that as a group, the irrigation projects averaged the highest cost overruns of any group of agricultural investments, the average cost overrun being 58.8 percent with a range of -10 percent to 175 percent on eight projects. These results were "consistent with similar experience of irrigation projects in earlier reviews."

Along with being costly, irrigation projects are often disappointing in terms of performance.

> Planning deficiencies....which cause major water wastage and/or environmental damage, have been particularly common during the recent rapid expansion of new irrigation development (4).

High costs and poor performance are not inevitable artifacts of irrigation development in developing countries. A first step towards more cost-effective projects, and perhaps, therefore, a greater food availability, is an enhanced understanding of the causes of cost overruns and poor performance.

FACTORS AFFECTING THE COST-EFFECTIVENESS OF IRRIGATION PROJECTS

Four key factors determine the cost-effectiveness of irrigation projects in developing countries:

- the physical environment of the project;
- its planning, design, and implementation;
- its operation and maintenance; and
- farm socioeconomics.

The Physical Environment

The physical environment of a project area is very important in determining the cost and therefore the cost-effectiveness of a project. Characteristics of the physical environment, in particular topography, soil structure and salinity, the amount and timing of rainfall, and the availability and quality of water resources dictate the need for project work and structures. Table 6 showed the range of costs in different regions. The range of these estimates is to a large extent accounted for by differences in the physical environments of the regions. A dry region with sandy soils requires a reservoir with a much larger storage capacity per unit of land than an area with clay soils and monsoonal rains. If one region thus requires a greater investment than another and both regions return similar benefits, the costlier project would be inherently less cost-effective due to the requirements placed on it by the physical environment.

While the physical environment is a major cost determining factor, it is not a factor which policymakers can influence. The best that can be done is to develop the areas that are most favorable to irrigation and to account for the prevailing physical conditions which may constrain agricultural production.

Project Planning, Design, and Implementation

The planning, design, and implementation of an irrigation project is a continuous process. This process determines how much of a project's potential is realized, both in terms of costs and benefits.

> The technical characteristics of a project place an upper limit on the level of performance which the human agents concerned (policymakers, project management and staff, and farmers) are capable of achieving (4).

A poor job of planning, designing, and implementing a project will affect the performance of a project throughout its lifetime. It is particularly important to understand and account for the limitations of the physical environment at this stage. The physical design of an irrigation project must rely on careful analysis of soil characteristics and water availability and quality (11). This is not always done, however, and as a result, irrigation efficiencies are typically low. Effective use of only 10-20 percent of the irrigation water "is by no means uncommon" (2) Bottrall states that "It is not uncommon for major projects to irrigate only one-half to two-thirds of their design command area adequately (11)." These low efficiencies result in high costs per unit of water applied.

It is important that more than just the physical constraints are understood and accounted for.

> The design of irrigation schemes for long-term stability must include not only engineering considerations of water storage, conveyance, and delivery, but also agricultural, economic, social, political, legal, and environmental considerations (16).

Agricultural, economic, and social considerations are of great importance. Project success ultimately depends on the farmers, as they actually produce the benefits derived from the project. Social or economic conditions, if not taken into account, can significantly reduce farmers' incentives to produce and therefore reduce the cost-effectiveness of the project.

Unfortunately, problems in the planning, design, and implementation process are all too common. In the World Bank's 1982 project review nearly all irrigation projects reviewed required design changes which significantly increased project costs. Some problems in design and planning translate directly into problems with implementation. Major design changes can lead to rework of the project's physical structures, and inadequate designs can result in inadequate physical structures. "In a large number of cases, failures, delays or other problems can be traced back to lack of appropriate project design..." (19). The World Bank attributes design failures to a lack of knowledge and understanding of the project area (19).

For example, insufficient preparation has led to poor performance in a number of projects in Thailand. Most of Thailand's irrigation development has been in an area called the Central Valley, a very productive rice growing region responsible for the bulk of Thailand's rice production for export. The Central Valley has soils which are high in clay--ideal for rice production. In contrast, the Northeast area of Thailand has soils which are very sandy, resulting in water losses through the soil from 3 to 20 times higher than

those of the Central Valley soils. Some years ago, several irrigation schemes were developed in the Northeast area of Thailand, primarily for rice production. The engineers who designed these schemes, rather than taking soil surveys for the project area, assumed that the soils were the same as those of the Central Valley and designed the projects with assumptions appropriate to the Central Valley area. Because the designs fail to account for the high water losses of the Northeast soils, less water is available than planned and the projects are not nearly as effective as was expected (9), (17).

In another example (project number 13, table 7), a failure to understand the socioeconomic environment resulted in reduced cost-effectiveness. The project was intended to increase rice production by rehabilitating and extending a relatively small irrigation scheme. Production of rice from the project area was expected to increase fivefold. However, project planners incorrectly assumed that the prevailing socioeconomic conditions of the area were favorable to intensification of rice production. In fact, though, paddy farming was considered an undesirable occupation, having low social status and yielding a much smaller income than other on- and off-farm activities. Paddy farming was only desirable as a means to produce food for family consumption. Because this fact was not known or understood, the irrigation system was designed for rice monoculture, unsuitable for any other crop. In the off season, only 33 percent of the project area is planted and in the wet season only 8 percent. In addition, farmers have not had the incentive to give up traditional paddy farming so the land that is planted is not cultivated as intensively as it could be.

These types of oversights, while typically producing less dramatic results, are common. They may occur because the governments involved lacks appropriate commitment to the projects. The interest of upper-level officials provides an incentive for lower level planners, designers, and supervisors to do a better job. Hence, the whole process of planning, design, and implementation is affected in a positive way. An example will serve to dramatize this point.

Project numbers 17 and 18 were both developed in the same country under the same loan. The performances of these two projects are dramatically different because the government was very concerned about one area and relatively uninterested in the other.

The region in which project 18 was developed was "a focal point of ... economic, social, and political development for many decades." The area was unstable, experiencing high unemployment and continuing migration of excess labor from the area. In addition, the population pressure on the cultivated area was very high. In contrast, the area in which project number 17 was located was not a focal point for development. In political terms, the region was not nearly as significant as that of project number 18.

While project number 18 was a great success, experiencing small cost overruns and higher than expected returns, project number 17 was a dismal failure. The costs were much higher than anticipated and the benefits much lower. The project lost 40 percent of the stored irrigation water before it left the reservoir.

It was not coincidence that these projects turned out as they did. The government had a great deal at stake in the development of the successful project, but relatively little at stake in the development of the failed

project. The government's commitment to the region in which project 18 was developed ensured that project's success.

Operation and Maintenance

Once an irrigation system is functioning, its operation and maintenance play a critical role in determining the short- and long-term success of the project. Even if a less than adequate irrigation system has been constructed, proper management of the system can minimize the adverse consequences and maximize the benefits. Water and management can be considered substitutable inputs to agricultural production. Poor management requires more water to produce an unstressed crop than good management (fig. 1). Thus, if for some reason (such as poor system design), water is available in reduced quantities, good water management can reduce or eliminate the adverse affects of the shortage (10).

A study of Pakistan's agricultural sector revealed low water-use efficiencies in the irrigation systems. The study concluded that inefficient water use was due to poor system operation and that improved management could produce "savings of over 20 percent...in the amount of water available for productive use." In Sri Lanka the introduction of strict management procedures in one project produced within a single season a 50-percent increase in rice production (4). Bottrall argues that programs to improve the operation of irrigation systems would yield great benefits:

> It may not be too fanciful to envisage the "water revolution" which could be brought about by these programmes as being analogous to the green revolution in its capacity to bring about major increases in crop production...(4).

Perhaps the worst aspect of poor system operation is the fact that it ensures poor performance in the future. Most irrigation schemes depend on the farmers to help maintain the physical structures. Farmers pay water charges to support maintenance costs, and may be expected to organize to do much of the work on the on- and off-farm distribution system. If the system does not provide reliable water deliveries, it is difficult to motivate the farmers to aid in the provision of the system's support (4). Consequently, the physical structures are not maintained properly and the system deteriorates, becoming less and less able to provide adequate irrigation.

Project number 1 experienced problems related to poor system operation. In this scheme, farmers were expected to provide for irrigation development on their own land, either by doing the work themselves or paying for it. Skepticism concerning the eventual availability of water made many farmers reluctant to make the investments of either time or money. The management of the system was set up in such a way that there was no supervision of the water delivery at the farm level. Farmers near the primary water outlets received an abundant supply of water while farmers more distant from the outlets received little or no water. In contrast, farmers in a pilot area of the project where water allocation was strictly supervised showed a great willingness to invest in land development.

In several other examples, poor system operation resulted in low recovery rates for water charges. In four areas that Bottrall (4) has studied, three of the areas had low water charges ($4 to $14.50 per hectare) and low recovery rates (48 - 70 percent). Bottrall attributes these poor recovery rates to

Figure 1. Relationship Between the Quantity of Water Required for Production of an Unstressed Wetland Rice Crop and the Degree of Irrigation Water Management

Source: (3), p.69.

"the low quality of water distribution received by the farmers." The fourth project, however, was able to collect much higher water charges ($87 per hectare) with higher recovery rates (97.8 percent) due to the fact that the system operation was much better.

Farm Socioeconomics

Favorable social and economic conditions on the farm are essential for the success of irrigation projects. The farm community's ability and incentive to produce agricultural goods is the core around which the benefit-producing side of projects are built. The enhancement of this core is the primary and often sole reason for the large expenditures of money and effort required for irrigation projects. Investments in these projects cannot be considered cost-effective if the farmers cannot or will not produce enough benefits to make the project worthwhile.

Farmers need not only the desire, but the ability to invest their own resources in an effort to increase production. This means that they must have the purchasing power to buy the inputs such as fertilizer and pesticides needed for enhanced production. If the farmers are too poor to afford these

purchases, the potential for agricultural production will never be achieved. For this reason, credit programs and input subsidies may be necessary in some areas. Farmers also need to be provided with proper incentives for production. This means that the prices they receive for their crop must provide them with a reasonable return for their labor and expenses. If not, farmers will either seek employment elsewhere, or produce low-value crops.

In Egypt, price control policies have produced an environment that provides farmers with signals to produce crops of low value. The price control policies dictate compulsory deliveries of major crops to the government at predetermined prices well below the international market prices. The government then resells the crops domestically or on the international market at substantially higher prices, "thus implying considerable profit margins for the state" (1). These "profits"--in reality taxes--are used by the government to fund development activities.

The taxes have substantially reduced farm profits, providing a considerable disincentive for production of the controlled crops. Farmers have reduced production of government-controlled crops in order to shift to less regulated crops.

> During the last decade strong gains in output were made for less-regulated products including berseem, maize, vegetables, fruits, red meat, chicken, milk and eggs. The output of strictly controlled crops, i.e. rice and cotton, generally decline[d]... Wheat, which was decontrolled in 1977, showed slight gains. The output of soybeans, with prices fixed at high levels, has advanced significantly (18).

Egypt's pricing policies have dictated a shift from the production of high-value export crops for which Egypt has a relative production advantage to crops of lower value. The production of crops for animal feed has increased (berseem and wheat straw), while as noted, cotton and rice have declined. The farmers have responded reasonably when the skewed pricing policies of the government are considered.

In addition to economic incentives and abilities, farmers must possess an adequate knowledge of agricultural practices, particularly the use of modern inputs, in order to maximize the benefits from these inputs. Farmers should know when and how much water, fertilizer and pesticide to use. Inefficient use of these resources can only result in the failure to realize yield potentials economically. Extension services become very important in helping farmers to maximize the benefits that can be returned from the project.

> Good agricultural extension is vital to the development of irrigated agriculture in developing country conditions, especially in the early stages of irrigation and/or when farmers knowledge of agricultural and irrigation techniques is limited (4).

Bottrall states that extension services are most often inadequate and reflect the "low priority given by most governments to extension - guarantee[ing] ineffective performance" (4).

Other factors can reduce performance and the farmer's willingness to grow certain crops. A previous example showed that social factors, such as a

stigma attached to paddy production, can be important. Extension agents have been trying unsuccessfully for a number of years to convince farmers in Northeast Thailand to adopt modern, high-yielding varieties of rice. Their efforts have been hampered, however, by the fact that the modern varieties do not possess the taste and cooking qualities that the Thais desire. Only the traditional glutinous, or sticky, varieties of rice are culturally acceptable. These are just two examples of problems with cultural or social acceptance of agricultural technologies. These types of problems might be resolved or accounted for if planners and designers understood the social environment with which they were dealing.

A FRAMEWORK FOR UNDERSTANDING LARGE IRRIGATION PROJECTS

An important step toward improving the cost-effectiveness of irrigation projects is to fully understand the causes of poor performance. A framework is developed here to help improve understanding by connecting the ideas and concepts discussed in the previous sections. This framework takes the form of a computer simulation model of the design, implementation, and operation of a large irrigation project in a developing country. The ideas and concepts which comprise this framework represent a collection from available literature, from project audits and evaluations, from conversations with persons involved in agricultural development; and from my own personal experience.

There are few specific insights in the model that are new. The model incorporates in a single, dynamic structure, concepts concerning biological and physical processes, project design and implementation, project operation and maintenance, and farm socio-economics.

Putting these concepts into a single framework is useful for several reasons. First, the computer provides a means for more accurate representation of a complex system. Less sophisticated models break down as we try to comprehend larger and more complex systems. We can get around this problem, though, if we focus on smaller subsystems, translating our understanding to mathematical equations. Combining equations from subsystems will then yield a reasonable representation, or model, of the whole system.

Second, the development of a simulation model enables a wide variety of policies to be tested, yielding insight into possible ways to correct undesirable behavior in the real system. In systems as large and costly as irrigation projects, this provides a means of inexpensively exploring avenues which might lead to increased cost-effectiveness.

Finally, the computer allows the dynamic behavior of the projects to be represented graphically, providing a picture which a verbal description cannot match. A look at how the model operates can furnish a deeper understanding of irrigation projects and how various factors determine the cost-effectiveness of these projects.

There are limitations inherent in this process. First, the process of modeling inescapably depends on the modeler's understanding of the real system, and upon skill in translating that understanding accurately into the mathematical equations which make up the model. Secondly, the model is nothing more than a representation of reality, an imitation, as all models must be. As such, all models are flawed as they cannot incorporate all the variables that produce the behavior of the real system. Nevertheless, models

can be very powerful tools for describing, explaining, and predicting the behavior of real systems. The purpose of the model presented here is to describe and explain the behavior of irrigation projects in developing countries, and to predict how certain policies may affect the projects.

Conceptual Overview of the Model

The model can be partitioned into four sectors for explanatory purposes: the biological and physical processes sector; the design, implementation and maintenance sector, the farm socioeconomic sector; and the project components sector. Figure 2 illustrates these sectors diagrammatically. As the arrows indicate, all of the sectors are interindependent. Each sector influences and is influenced, directly or indirectly, by the other sectors. The quality of the design and implementation process determines the ability of the physical structures to adequately irrigate the project area. The irrigation affects the productive capacity of the area which in turn has its affect on the economic position of the families in the farming community. In addition, credit and extension, which can be included as project components, are important in increasing farmers' purchasing power and their ability to apply fertilizer efficiently, thus affecting yields. The farmers' financial position and the reliability of the irrigation system determine the level of maintenance expenditures, which in turn affects the ability of the irrigation system to deliver water. Factors determined outside the project boundary are important in determining system performance. The political interest of the government (here called political will) influences the design and implementation process; prices which farmers pay and receive affect the profitability of their operations; and the amount and timing of rainfall determine the irrigation water required for production.

Model Description

The conceptual overview provides a broad brush look at important elements of the model and their interactions, showing that the model is dynamic and complex, as irrigation projects are. The following description of the major elements of the model's sectors uses flow diagrams to illustrate the structure of the elements.

Figure 3 illustrates the symbols used in the flow diagrams. A level is a state variable. It represents a stock of something such as water, shoes or money, but can also represent stocks of nonmaterial things such as experience, quality, or morale. The value of a level depends on the previous value of the level as the model steps through time, and the change as determined by the rate variables. Rates act as valves controlling the flow into and out of the level. When a stored item goes into or out of a level, it must come from or go to another level, or a source or sink, depending on the direction of flow. If an item comes from or goes to a source or sink, that indicates that the item's origin or destination is not of interest.

Rates are ultimately determined by levels and constants, but are often determined by intermediary variables called auxiliaries. Auxiliaries serve as intermediate variables to clarify theories and concepts. The value of an auxiliary variable is recalculated for every time period.

It should be noted that in the flow diagrams that follow I have chosen to emphasize understanding over accuracy. The flow diagrams illustrate only what

Figure 2. Conceptual Overview of the Model's Structure

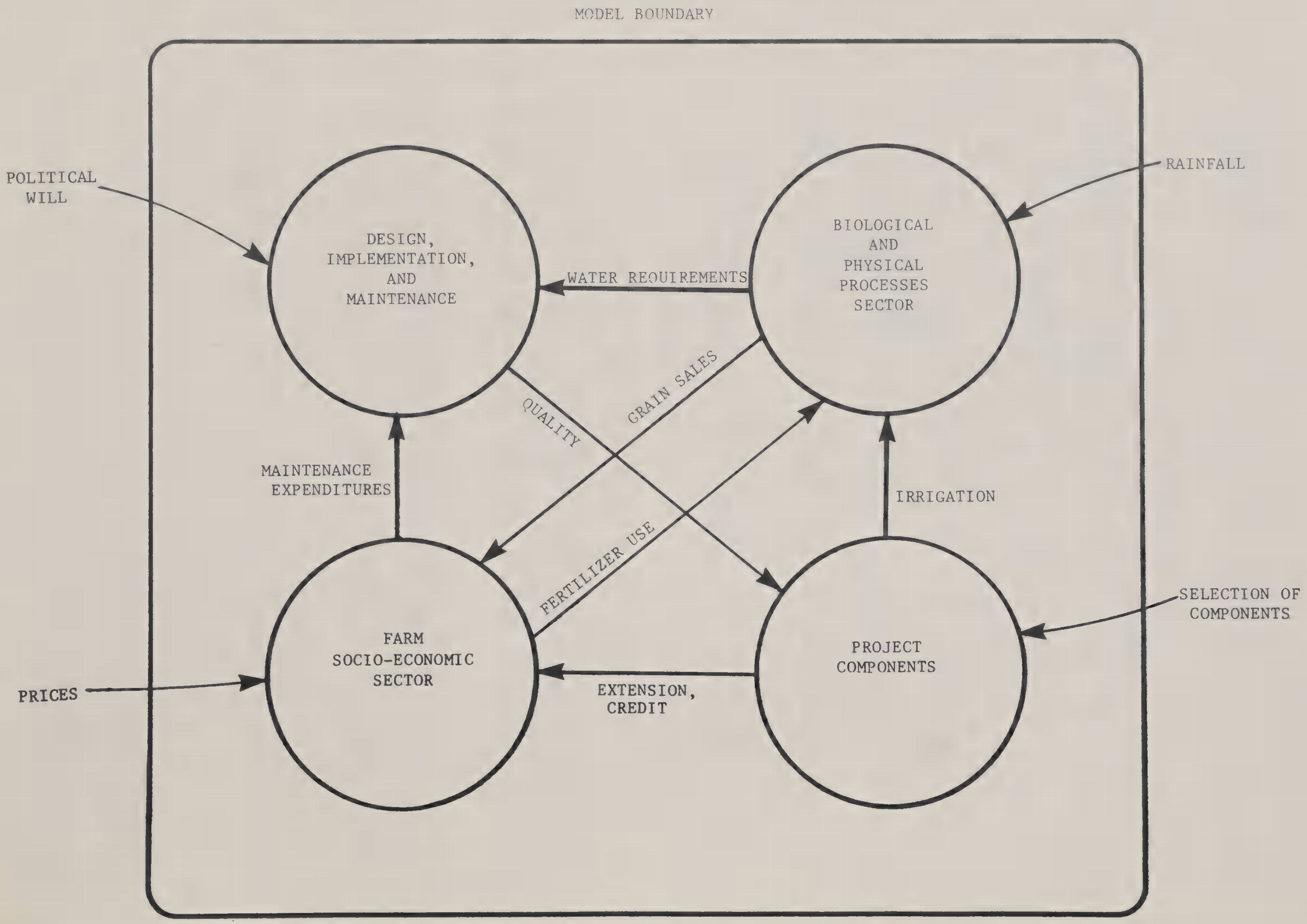
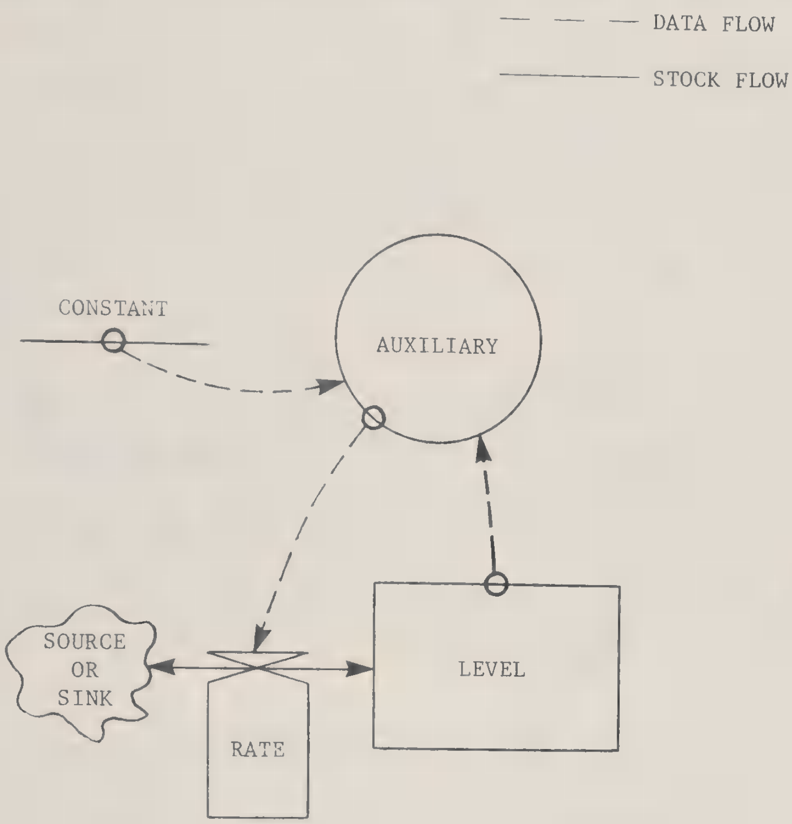


Figure 3. Symbols Used in System Dynamics Flow Diagrams



is necessary for understanding, and do not always show intermediary variables or all of the concepts contained in the model.

Biological and Physical Processes

The biological and physical processes sector captures plant growth and the essential factors determining plant growth. Figure 4 illustrates the major elements.

The primary agricultural activity in the model is the production of rice. The material production of rice occurs by the process of grain fill, which is the culmination of the interaction of biological and physical processes. The plant's ability to manufacture and store starches and proteins in the form of rice depends on the photosynthetic ability of the plant. The photosynthetic potential of the plant in turn depends on the amount of green vegetation and on the variety of plant being grown. Physical constraints may be present which prevent the plant from realizing its biological potential for rice accumulation. Water and nutrient deficiencies, particularly nitrogen, are the most common constraints to high yields. Shortages of water not only slow growth but can also cause the spikelets (the rice flower) to die, making them unable to accept starches and proteins for storage.

Figure 5 illustrates the accumulation of vegetation and grain for a traditional rice variety prior to irrigation. Vegetation grows exponentially at first, then, as the plant approaches the reproductive phase, vegetation accumulation slows, then stops. As the reproductive period begins, the plant begins to store starches and proteins in the spikelets. This process slows as the plant matures. Finally, the plant is harvested and the levels of

Figure 4. Flow Diagram of Essential Elements Determining Rice Growth

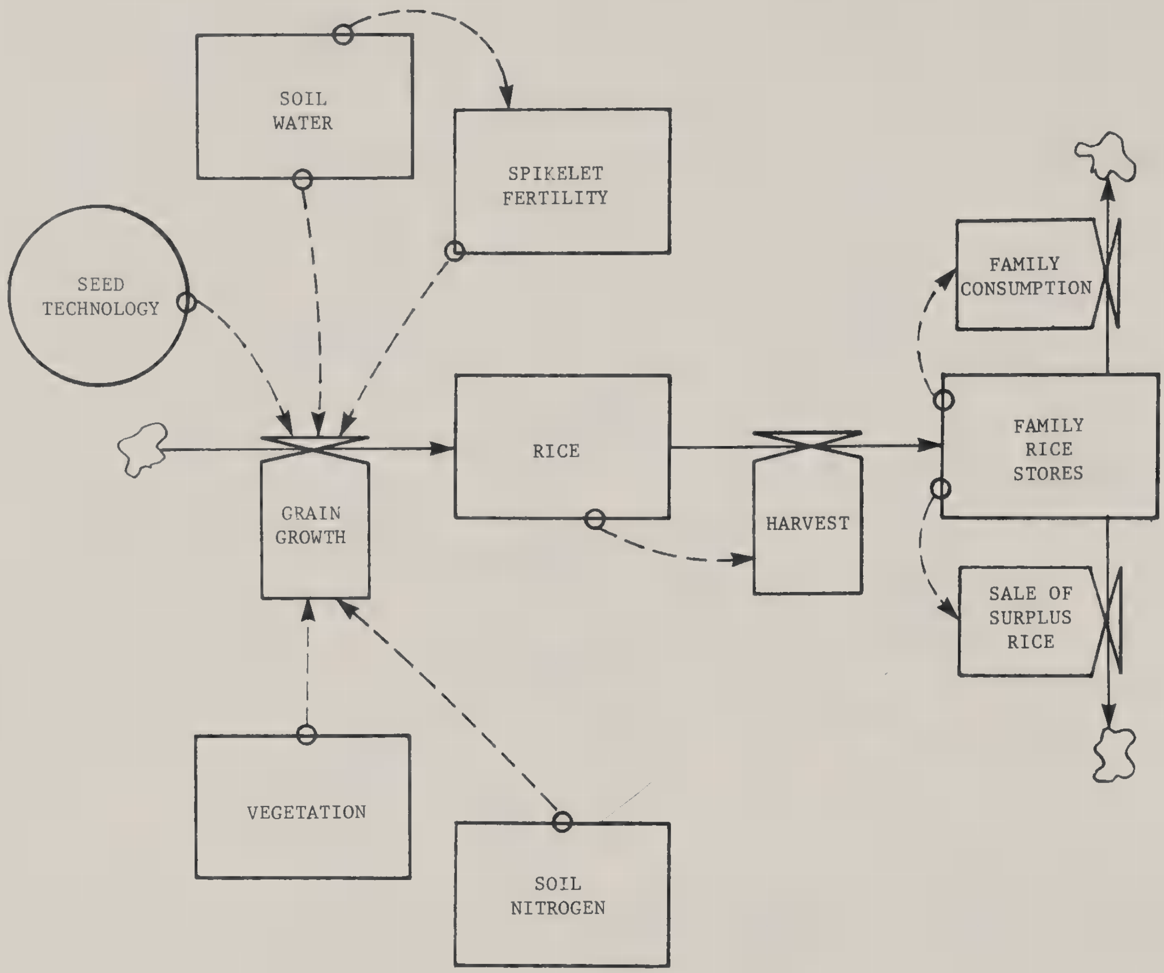
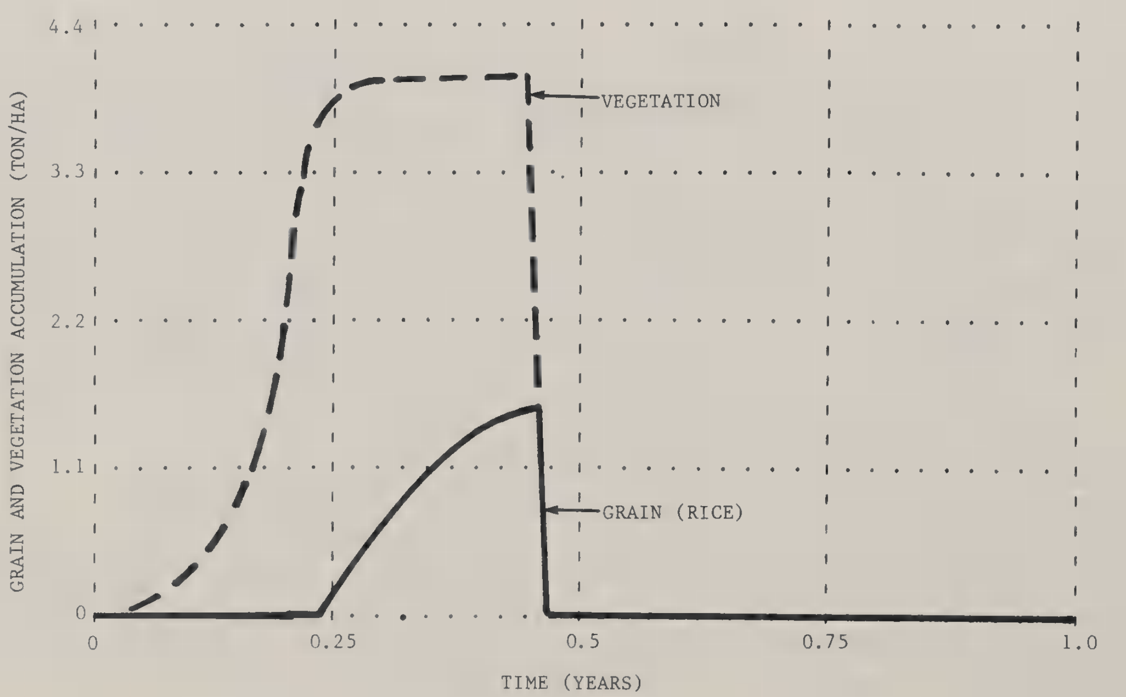


Figure 5. Model Simulation of Vegetation and Rice Accumulations Over A 1-Year Period Prior to Irrigation



vegetation and grain fall to zero. Without irrigation, there is not enough water for a second crop, so no plant growth is shown in the second half of the year.

The model is parameterized for a monsoonal rainfall pattern as Figure 6 shows. The rate of rainfall is bell-shaped, growing in intensity and then falling off. The area under the rainfall curve represents the total amount of rain which has fallen in the year. In the model, the amount of rainfall varies randomly around a mean, but the shape and timing of the rainfall pattern remain constant from year to year.

Figure 6 also shows the level of water in the top 6 inches of the soil. This soil depth, called the plow layer, acts as a reservoir, holding water for plant use. The level of soil water increases as the rainfall intensifies, until the vegetation grows to the point where transpiration losses become high. As rainfall intensity drops, soil water losses continue to exceed the infiltration rate until the plants are harvested and transpiration stops. At this point the soil water is replenished by the remainder of the standing water above the soil, and finally evaporation causes the soil to dry. In bad years, the dip in soil water which occurs between time 0.3 and time 0.45 can be severe enough to cause drought stress in the plant, significantly reducing crop yields.

Figure 7 shows the level of available nitrogen in the soil. The spike early in the run is caused by the first application of fertilizer. Plant growth and leaching remove nitrogen from the soil, so the level of nitrogen falls sharply as vegetation accumulates and rainfall intensifies. A second fertilier application keeps the bottom of the trough from dipping lower. As the soil dries and heats up in the second half of the year, the decay of soil organic matter brings the available nitrogen back to its original level.

Project Design, Implementation, and Maintenance

In order to make perfectly clear what is happening in this sector of the model, I must first point out that I have not built into the model the capability to plan an irrigation project. I have assumed instead that the selection of the project's components--irrigation, extension, and credit, are decided on prior to project initiation. The irrigation component is always included, but the inclusion of extension and credit programs become policy variables which can be tested for their effects on the success of the project. The model does not have the ability to choose certain parameters of the project such as the size of the project area or the reservoir. These parameters have been selected so that under good circumstances, the physical structures will be able to provide a reliable and adequate supply of water for the continuous production of rice.

The first step in project design is to collect the necessary information concerning characteristics of the project area. Soil and socioeconomic surveys must be done so that the project designers fully understand the project area. Figure 8 illustrates the process of information collection. A certain amount of project information is required to complete an adequate design. If there is a discrepancy between the necessary project information and the amount of information actually collected, the design will be less than adequate. The amount by which the design falls short is determined by the magnitude of the information discrepancy. In general, the greater the information discrepancy, the poorer the design.

Figure 6. Model Simulation of Rainfall and Soil Water Over A 1-Year Period Prior to Irrigation

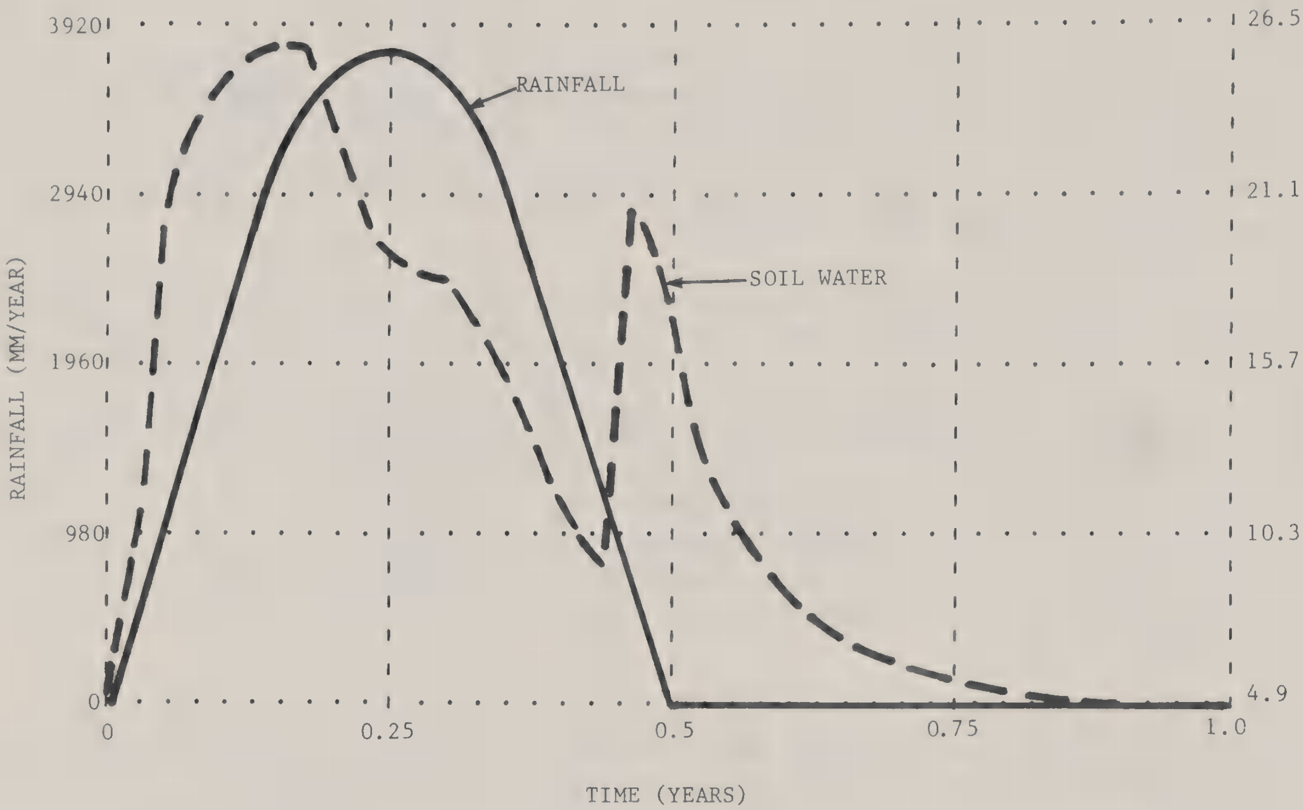


Figure 7. Model Simulation of the Level of Available Nitrogen

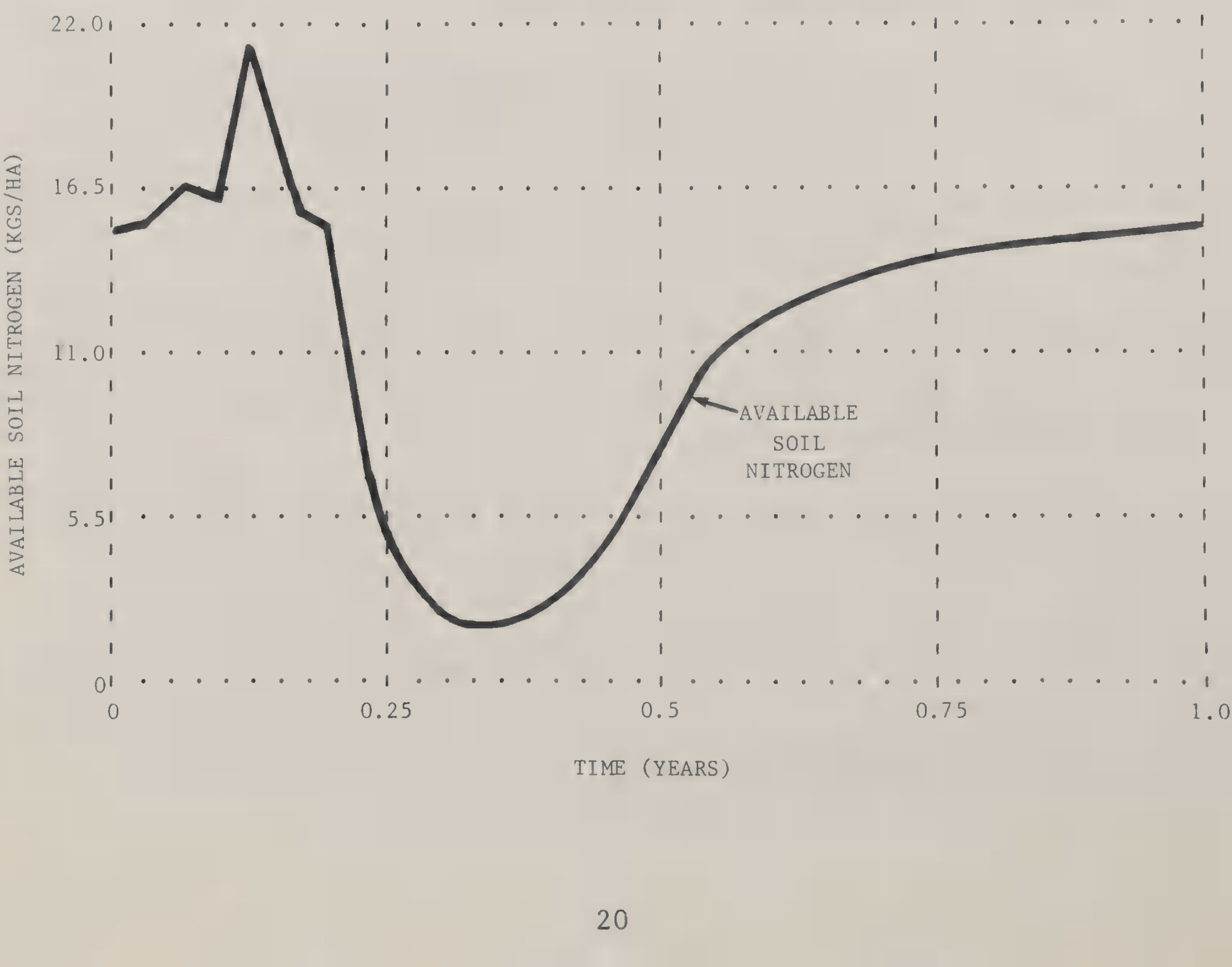
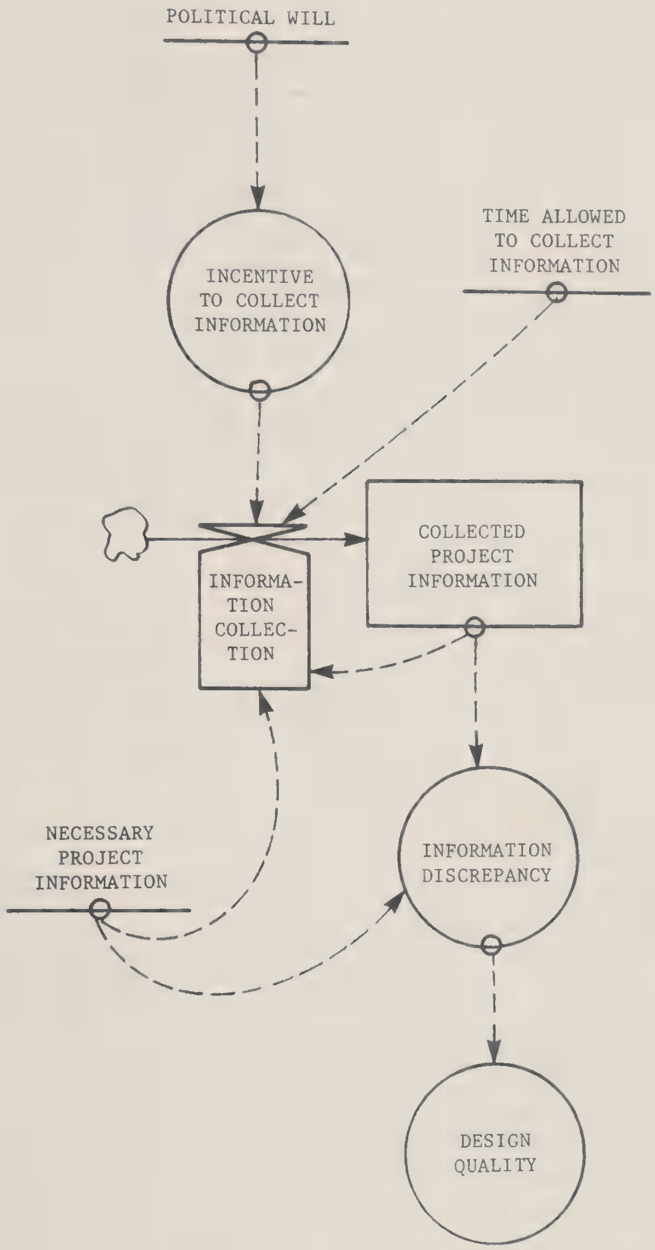


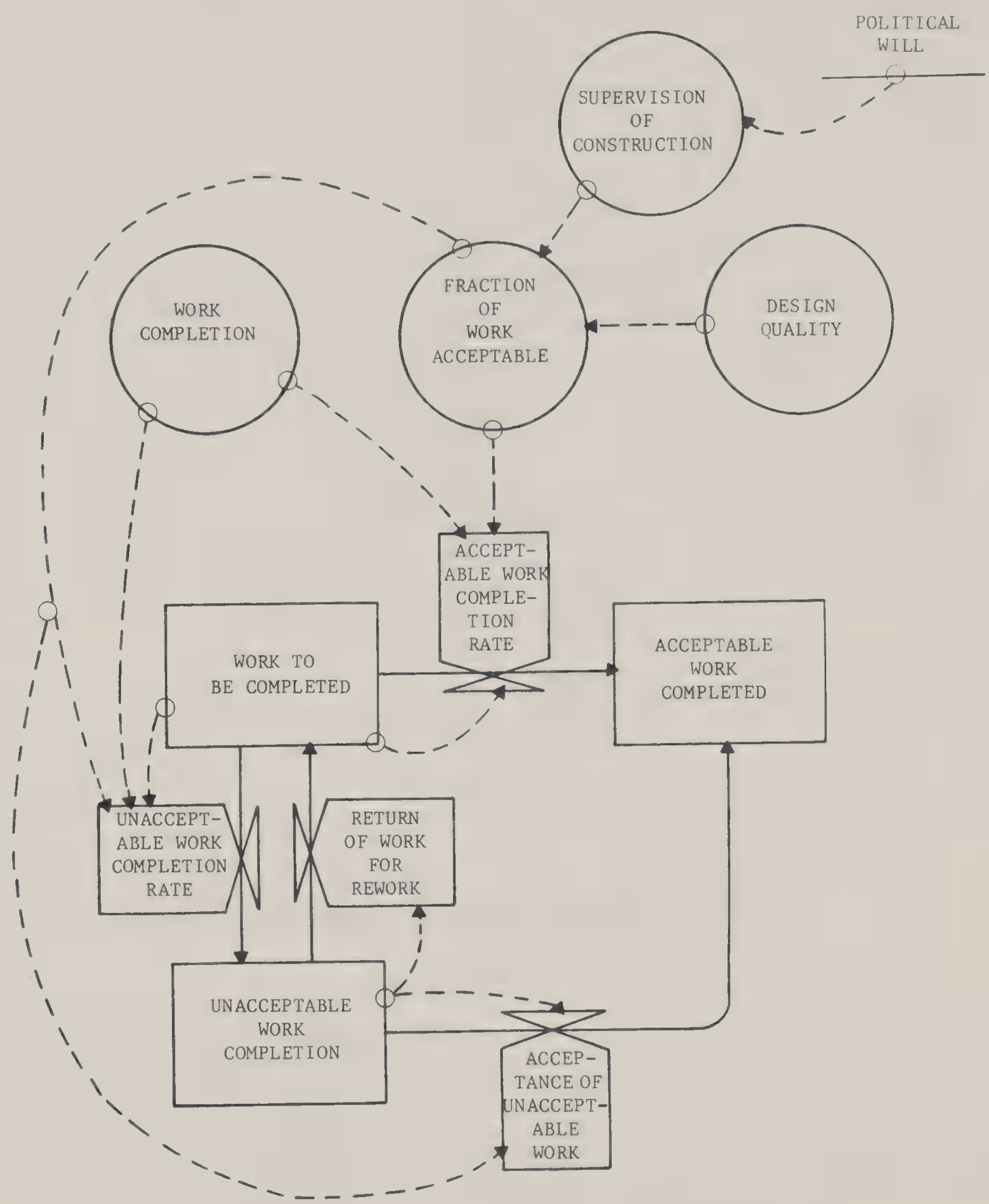
Figure 8. Flow Diagram of the Model's Information Collection Process



The amount of information that is collected depends upon the motivation of the information collectors, the time allowed for collecting the information, and the size of the information collection staff. Political will acts here as a key factor in motivating the information collectors.

When the period for information collection and design is over, the construction of the project's physical structure's begins. Figure 9 shows the logic of the project implementation. According to the project plan, a certain amount of work must be done to construct the physical structures of the irrigation system. This work can be done in an acceptable or unacceptable manner. At the time that it is done, all of the work is thought to be acceptable. In reality though, some of the work that is done is not acceptable, and after some delay this fact is discovered. The completed work that is discovered to be unacceptable is then returned to be reworked, or if time is very short it may be left undone and accepted as adequate.

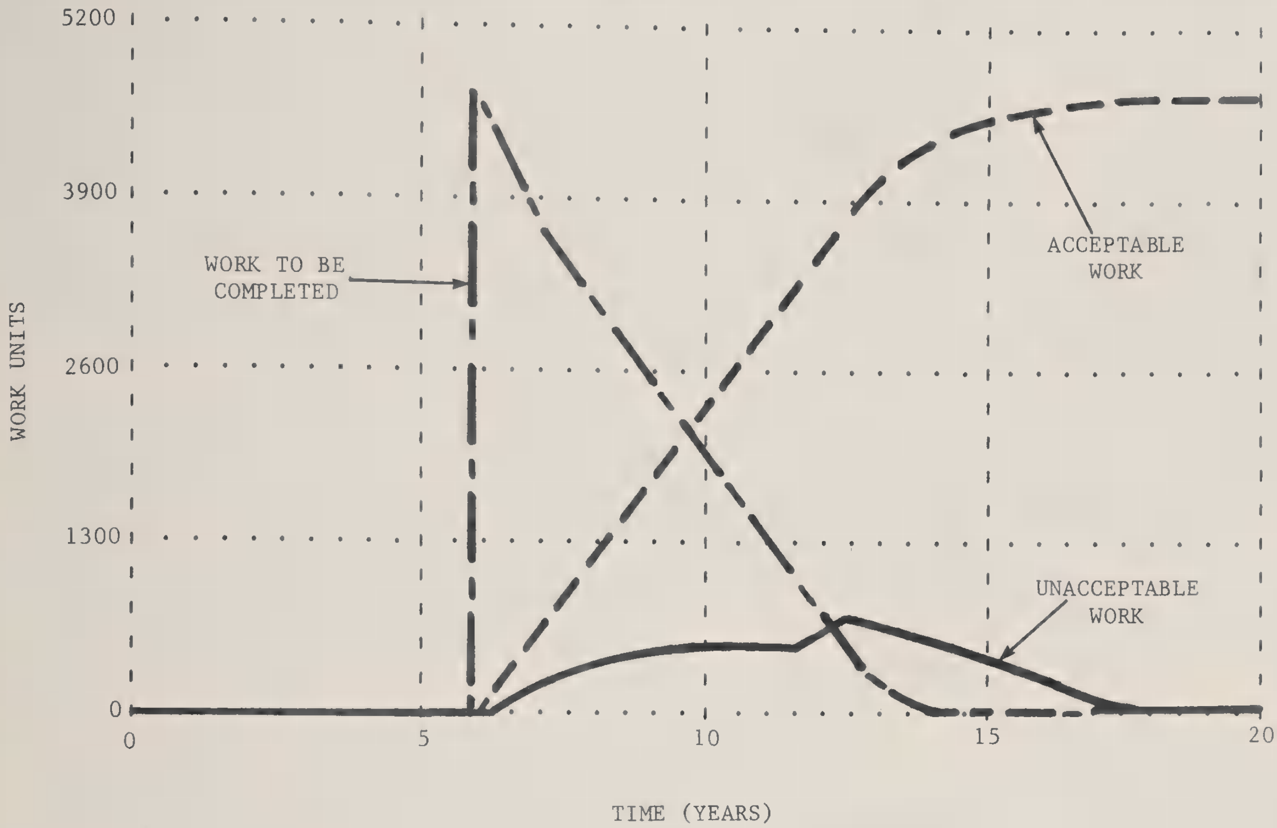
Figure 9. Flow Diagram of the Project Implementation Process



The rates of acceptable and unacceptable work completion depend on the size of the construction crew and upon the fraction of work that is acceptable. The fraction of work acceptable is a function of the design quality and the quality of the supervision which the construction crew receives. The quality of supervision in turn is a function of the political will of the government and the time remaining till, or since the estimated completion date.

Figure 10 illustrates the implementation of the project's physical structures. When the design period is over the work required for project completion is placed in the "Work To Be Completed" level. This amount of work must eventually be done in an acceptable manner and some of it will have to be done twice. At any one time there is not much unacceptable work to be redone, but the sum of the work that must be done twice amounts to a significant fraction of the total project work. The work that is done twice must be paid for twice. This rework is the source of cost overruns in the model.

Figure 10. Model Simulation of Project Implementation



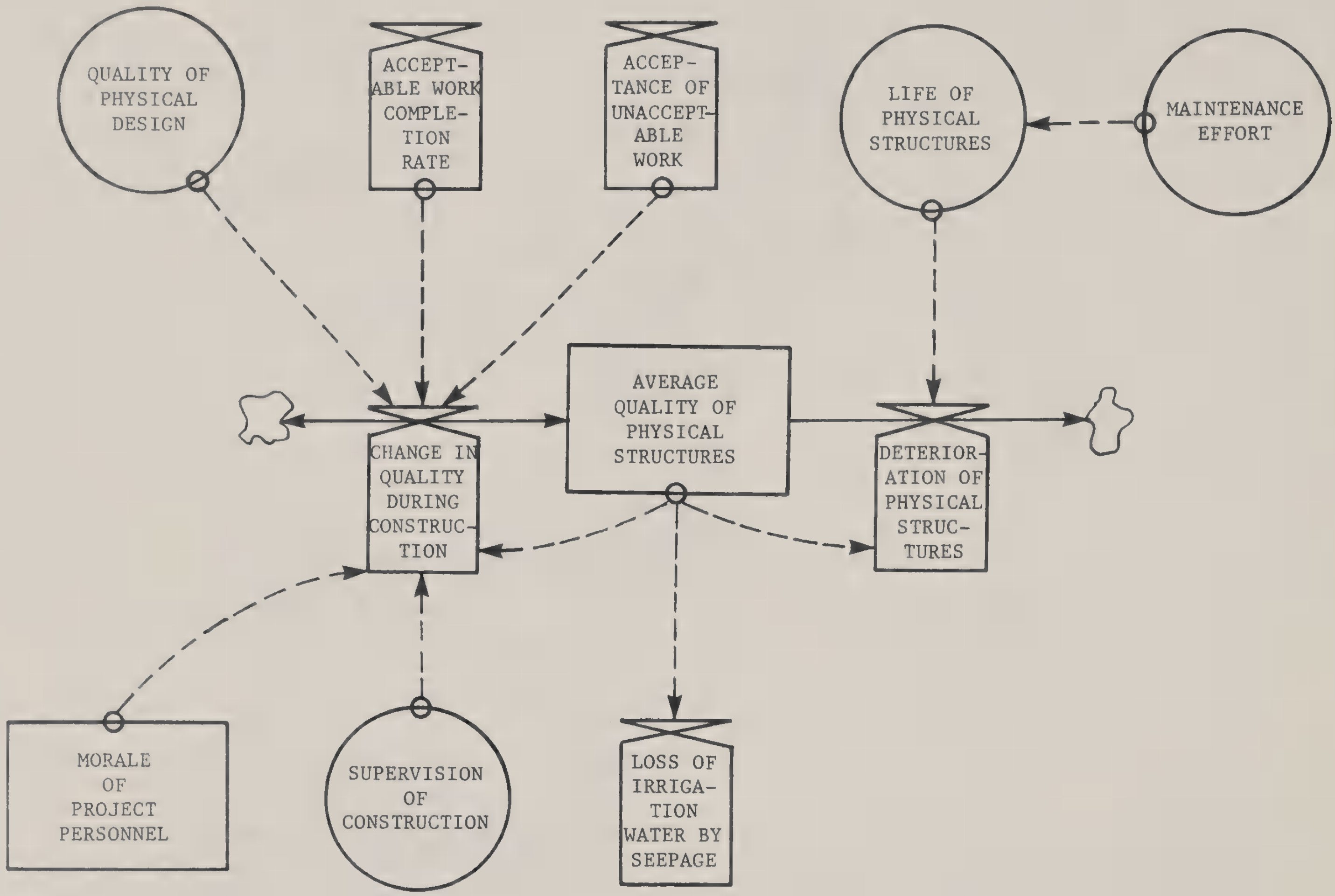
The quality of the physical structures is an important determinant of the availability and reliability of the water deliveries. The model structure for determining the average quality of the physical structures is illustrated in Figure 11. The quality of the physical structures changes during two phases of the project's life: construction and operation. During construction, the quality of each piece of work is averaged with the quality of the previous work that has been done. The quality of the current work depends on the quality of the physical design, the supervision of the construction work, and the morale of the construction crew. Supervision, as noted previously is a function of political will, and the morale of the construction crew depends on the amount of work returned for rework.

During the operation phase of the project's life, the quality of the physical structures inevitably deteriorates. The rate of deterioration is a function of the life of the physical structures. For example, if the life of the project is 50 years, one-fiftieth of the average quality of the physical structures will be lost each year. The life of the physical structures is determined by the effort put into maintaining the structures. While the process of deterioration cannot be stopped, it can be slowed if the system is properly maintained and the stream of benefits can be extended over a longer period of time.

The average quality of the physical structures determines the rate of water loss through seepage in the system. As the system deteriorates more and more water is lost during delivery, and the water use efficiency falls.

Farm Socioeconomics. The farmers' ability and incentives to increase their agricultural production lies at the heart of the success of an irrigation

Figure 11. Flow Diagram of the Model Structure Determining the Average Quality of the Physical Structure



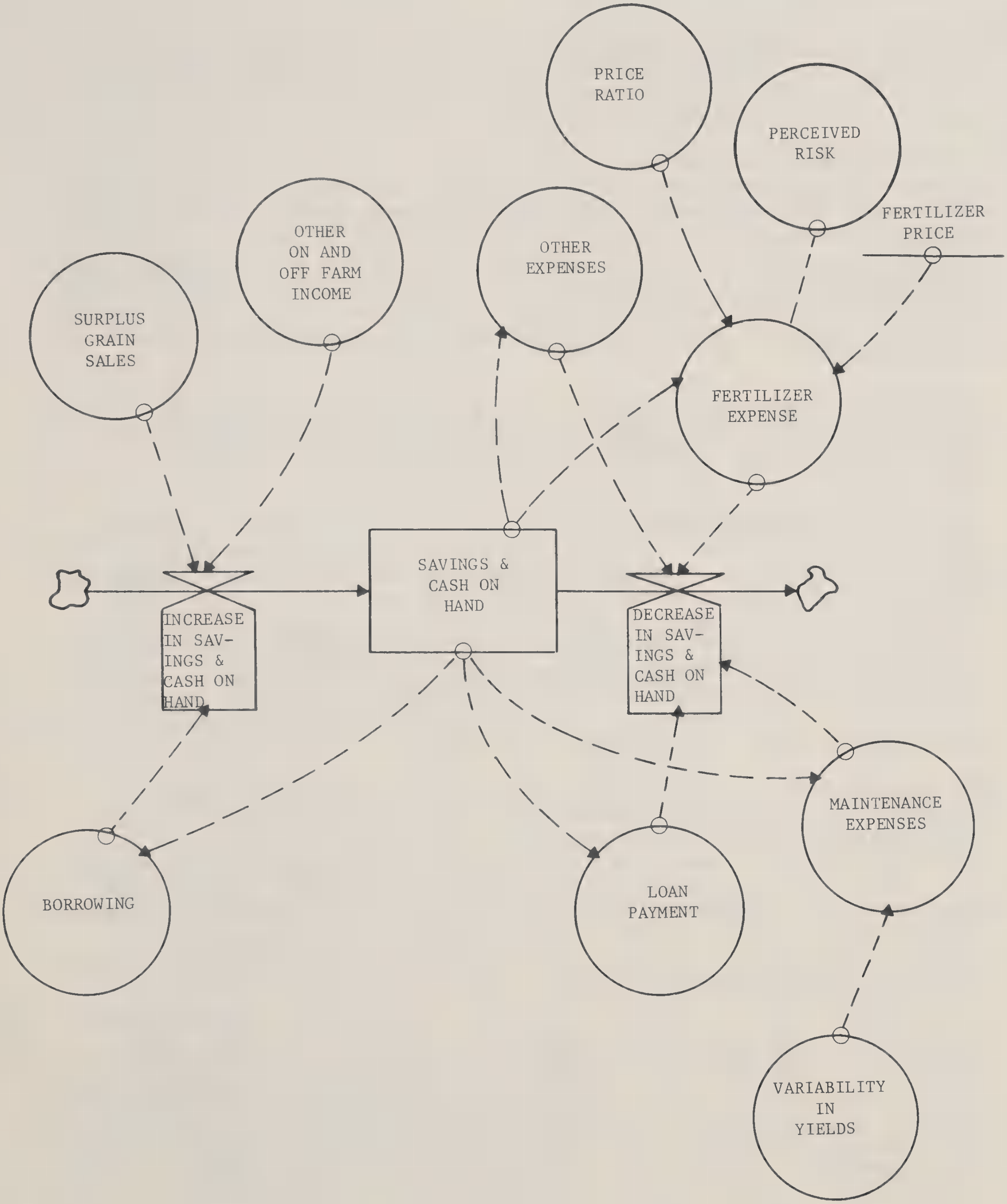
project. The farmers must have the desire and financial resources to purchase production inputs and the knowledge to use those inputs efficiently. Figure 12 shows the framework of the farm finances.

The level of savings and cash on hand is the farm family's expendable money. Expenditures include debt payment, maintenance costs, fertilizer costs, and other expenses such as family support and agricultural production expenses. All expenditures are dependent to some extent on the availability of funds.

For example, normal loan payments are determined by the amount of the loan, the life of the loan, and the interest rate. If enough money is available, that is, if the farm family is liquid, the normal loan payment is made; however, if liquidity is low, a smaller payment is made. Similarly, maintenance expenditures are determined by liquidity and yield variability, a function of rainfall and system operation. Fertilizer use and its cost is a function of liquidity, the grain-to-fertilizer price ratio, and the farmers' perception of the risk involved. Other expenses are simply a function of liquidity.

The level of savings and cash on hand is increased by grain sales, other on- and off-farm sources of income, and borrowing. On-farm income from secondary activities continues to come in at a constant rate throughout the year, but off-farm income is generated only in the dry season when irrigation does not

Figure 12. Flow Diagram of the Model's Farm Finance Structure



exist. When the irrigation system is in operation off-farm income is zero. I have not built into the model the farmers' decision structure for choosing on- or off-farm work in the dry season.

Borrowing is determined by the farmer's need and ability to borrow. When liquidity is low, farmers will borrow short-term to meet their consumption as well as production expenses. The banks will lend as much as 60 percent of the value of the expected grain surplus from the next harvest.

Figure 13 illustrates the farm family's savings and cash on hand over a 1-year period. The year starts out with a dip because the farmer has just left an off-farm job to start growing rice. Through the wet season, the family gets along by borrowing until the crop is harvested. With the sale of grain and new off-farm employment, the dry season starts with the family in a very good financial position. The farmer must now pay the accumulated debt and buy the items that the family has had to do without. The loan payments and increased consumption bring the family back to the same financial position as when the year started.

Figure 14 shows that the financial cycle of the farm family is one of borrow-repay/borrow-repay. During the wet season the family must borrow to meet its expenditures, which are at a minimum. After the harvest the short-term debt which has accumulated must be repaid.

The ability to borrow increases the farmers' ability to invest in production inputs such as fertilizer. The farmer's ability to use the fertilizer efficiently and his desire to use fertilizer are enhanced by his knowledge of and experience with fertilizer. Figure 15 shows the essence of the farmer experience structure. Experience cannot be lost, only gained. Farmers gain experience first, by actually using fertilizer, and second, learning through extension programs. The only way that farmers can achieve maximum experience is through a combination of first-hand experience and extension. Extension helps this process of learning not only by providing knowledge, but also by decreasing the time it takes farmers to learn.

The level of farmer experience with fertilizer is important for three reasons. First, the farmer's experience determines his perception of the risks involved in fertilizer investment. If the farmer has never used fertilizer before, the use of fertilizer will have more uncertainty attached to it than if the farmer has used fertilizer for many years. If the risks seem greater, the farmer will be less likely to invest in fertilizer. Second, the farmer's experience with fertilizer determines ability to use the fertilizer efficiently. The timing of fertilizer application is very important for maximizing the benefits of the fertilizer use. If the fertilizer is applied at the times when the plant most needs it, the yields will be high. However, if the timing is poor, yields will be low. For example, if all the fertilizer is applied one time at the beginning of the year, the result will be lush vegetation and poor grainfill, because all the nutrients will have been taken up during vegetative growth or lost through leaching. Finally, greater experience increases the likelihood that farmers will be aware of seed technology and agreeable to it. The acceptance of seed technology is also determined by cultural factors which cannot be superseded by experience.

The combination of influences which experience has on fertilizer use, efficiency, and seed technology can have a dramatic effect on yields.

Figure 13. Model Simulation of a Farm Family's Savings and Cash on Hand Over a 1-Year Period Prior to Irrigation

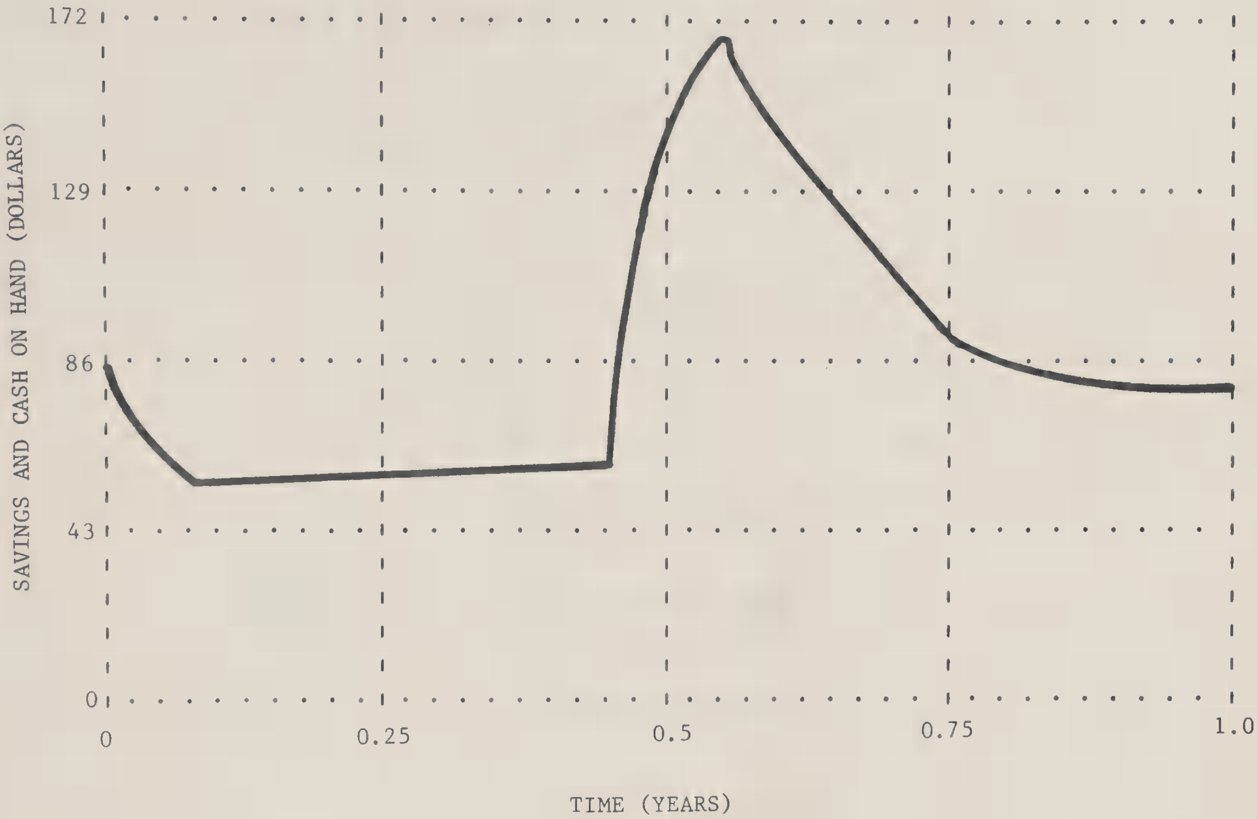


Figure 14. Model Simulation of a Farm Family's Short-Term Borrowing and Short-Term Debt Payment Over a 1-Year Period Prior to Irrigation

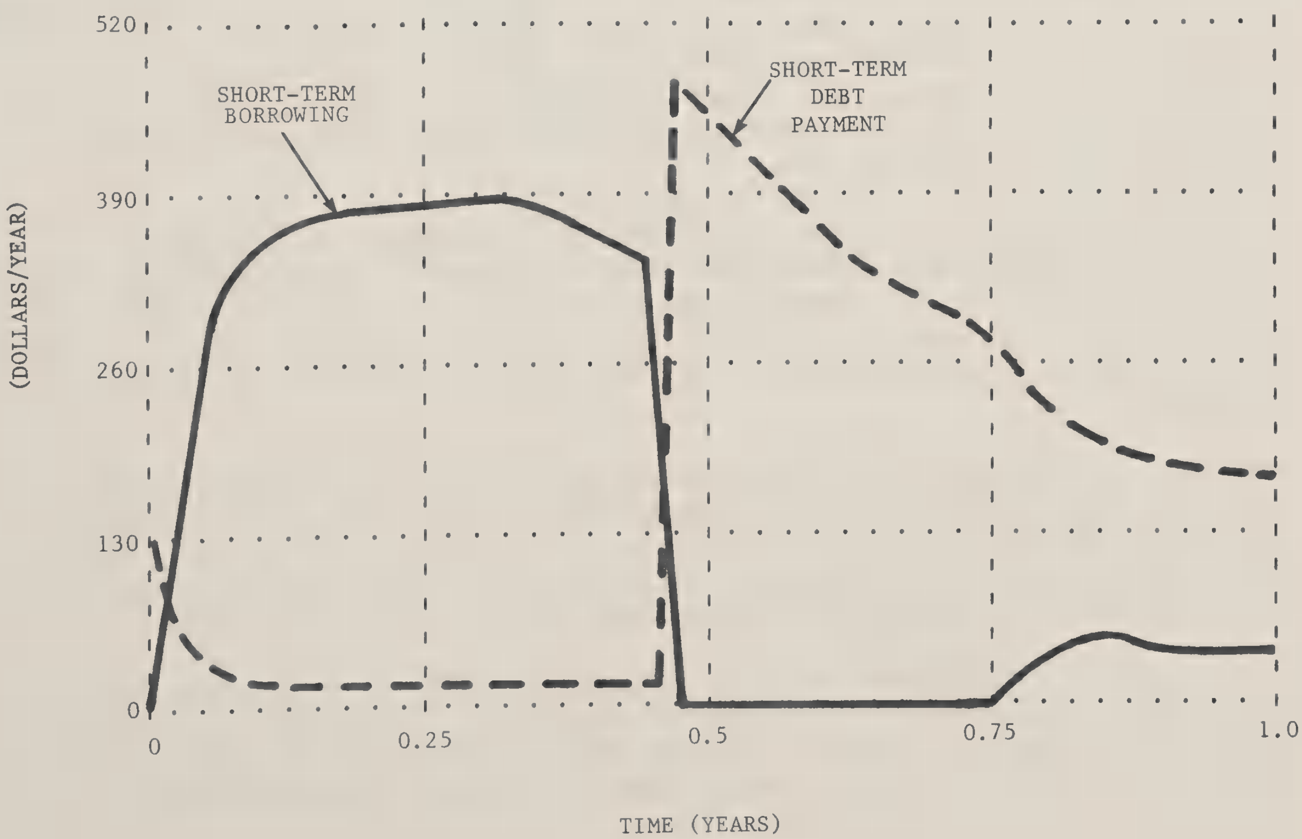


Figure 15. Flow Diagram of the Model Structure Determining Farmers' Experience with Fertilizer

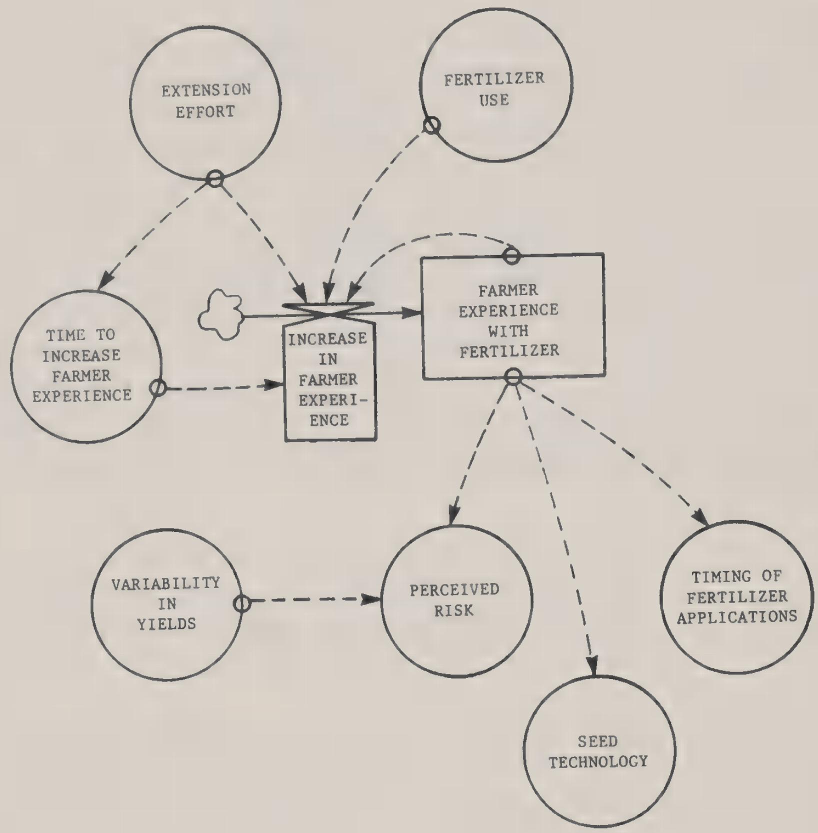


Figure 16 compares two computer simulations with different levels of farmer experience. One could imagine that these simulations were of adjoining farms. Soil and rainfall are identical, as are farm finances at the beginning of the year. The farmer with a great deal of experience invests more heavily in fertilizer and uses it more efficiently than the less experienced farmer. As a result, the experienced farmer's yield is more than 50 percent higher. Neither farmer in these simulations has adopted much seed technology as cultural factors prohibit this.

Project Components. There are three project components in the model: irrigation, extension programs, and credit programs. The irrigation component is part of every project modeled, while extension and credit are policy variables. The extension and credit programs are relatively simple, providing extension and/or credit based on the need and the government's perception of the need.

The need for extension is a function of farmers' levels of experience, and the need for credit is a function of the borrowing discrepancy, which is the difference between what the farmers want to borrow and the level of funds actually available for borrowing. The government's perception of these needs is based on the socioeconomic information discrepancy (figure 17).

The project's irrigation component is more complex. The framework for the irrigation component is illustrated in figure 18. Water is collected and stored for irrigation from the flow of river water. Some of the stored water is lost to evaporation, and some is lost to seepage. Evaporation is a

Figure 16. Model Simulations of Rice Accumulation Prior to Irrigation, for Two Farmers with Different Levels of Experience

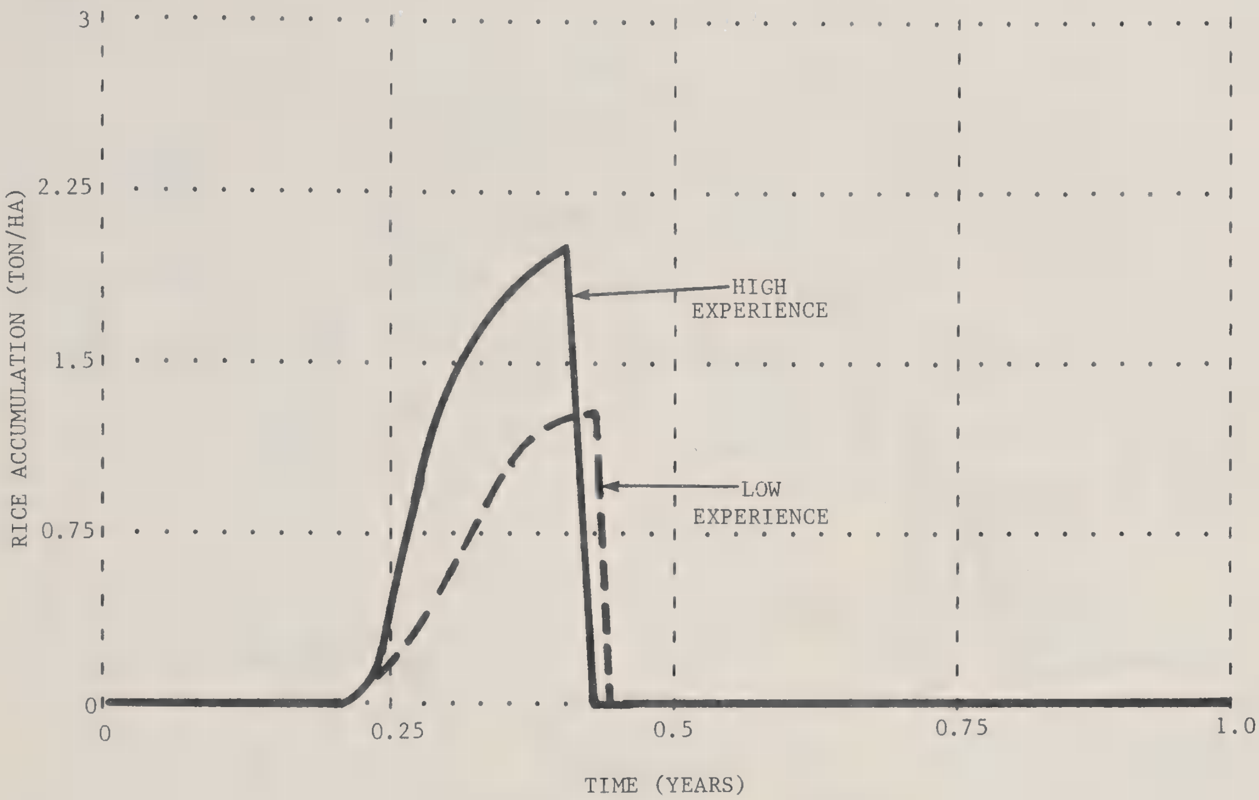


Figure 17. Flow Diagram Illustrating the Determination of Extension Effort and Credit Availability

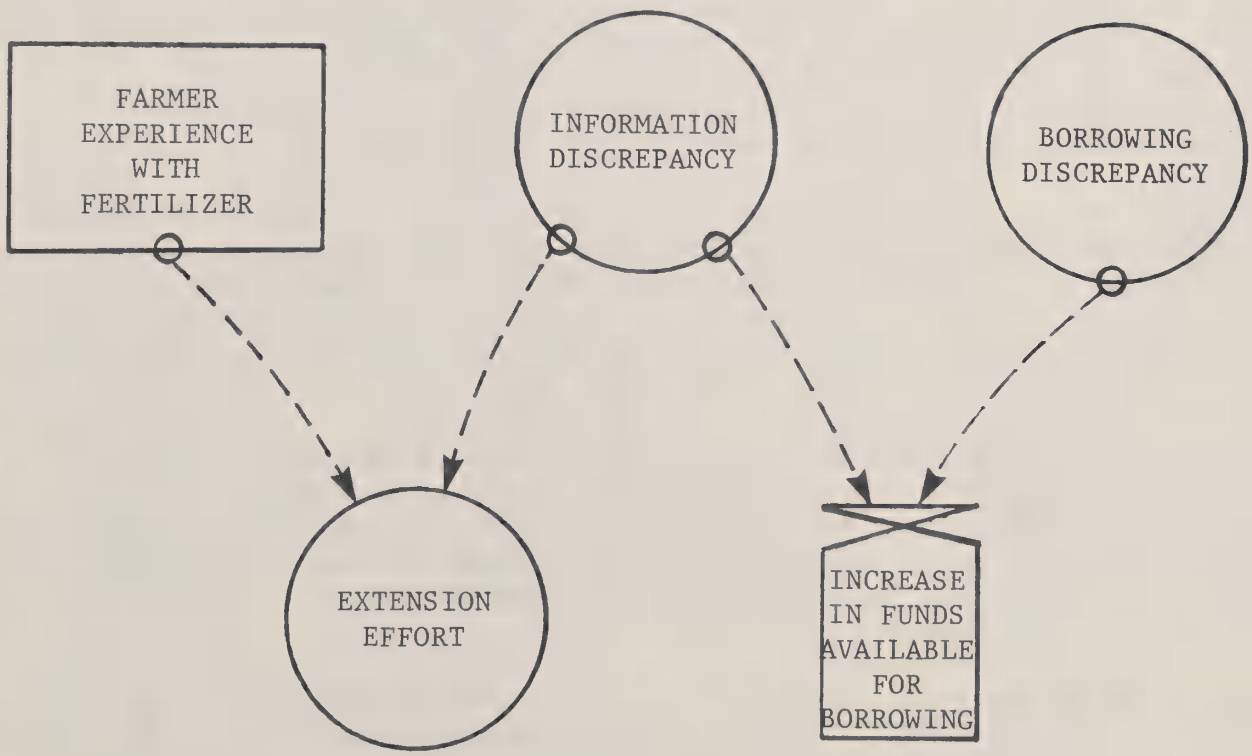
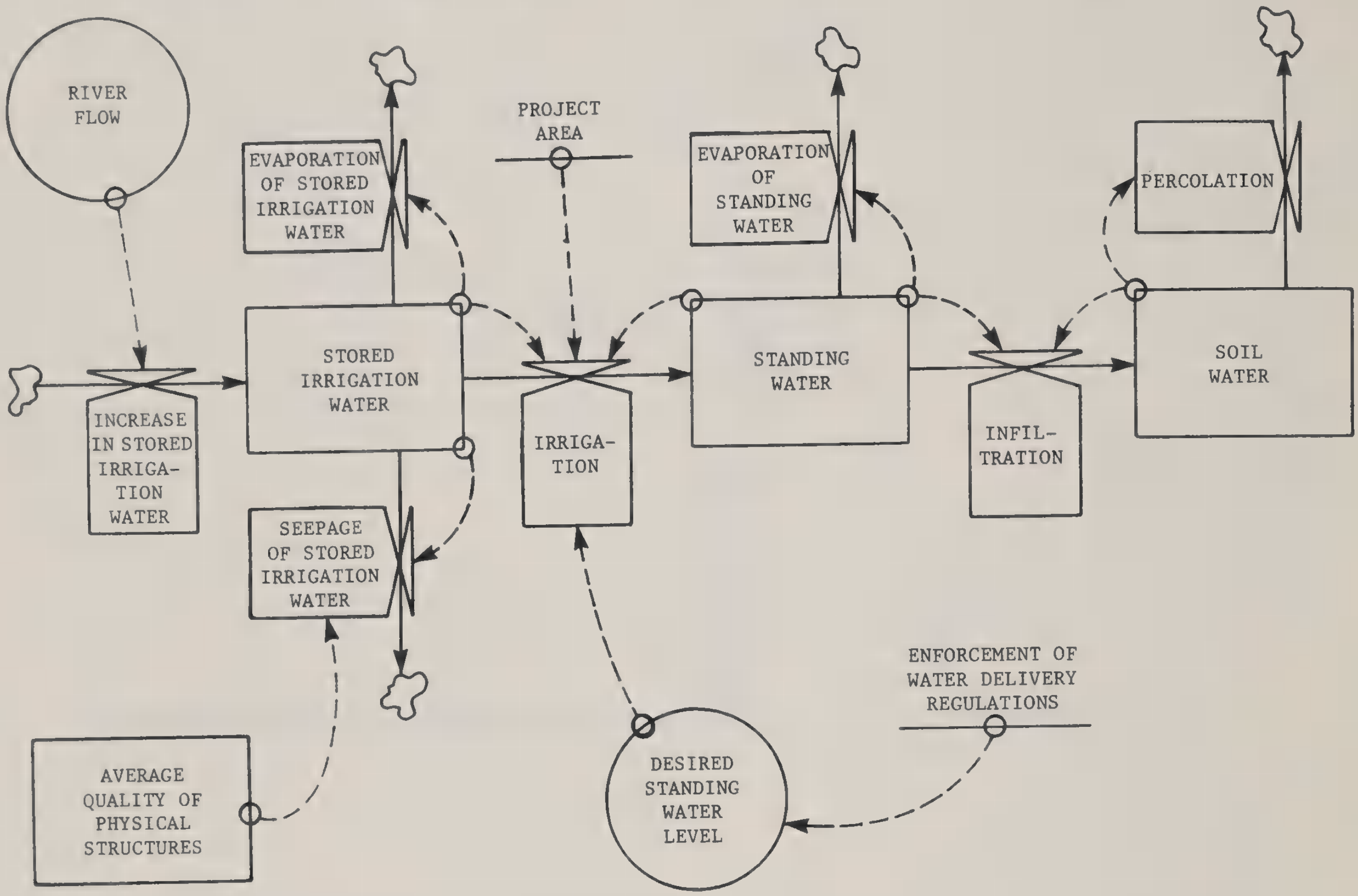


Figure 18. Flow Diagram Showing the Model's Irrigation Component



function of environmental conditions and the surface area of the reservoir. The rate of water seepage, or the leakiness of the irrigation structures, is determined by the average quality of the physical structure and characteristics of the soil. The greater the rates of seepage and evaporation, the less water is available for irrigation.

Irrigation, then, is determined by the availability of irrigation water and the amount of irrigation water desired. In rice cultivation, farmers typically put up short embankments called bunds around their fields to keep the water from running off. Irrigation supplements this reservoir of water standing on the fields. The structure of the model is such that the farmers try to maintain a certain level of water on the fields. If there is no management or enforcement of the water allocation rules, each farmer will try to maintain a higher level of standing water than is necessary, leading to inefficient water use. The higher standing water levels mean wetter soils, which in turn lead to greater losses of irrigation water to deep percolation. As more irrigation water is used, the water behind the dam is depleted. In the dry season this may mean that water deliveries will be inadequate and drought stress may reduce yields.

Figure 19 shows the level of stored irrigation water through a 1-year cycle. Soon after the rainy season starts, the reservoir begins to fill. As the rainfall intensity slows, more and more of the stored water is used for irrigation, and the reservoir is depleted. Figure 20 shows the rates of river flow and irrigation during the year. The flow of the river exhibits a sinusoidal pattern corresponding to the monsoon. The irrigation rate is also

Figure 19. Model Simulation of the Level of Stored Irrigation Water Over a 1-Year Period

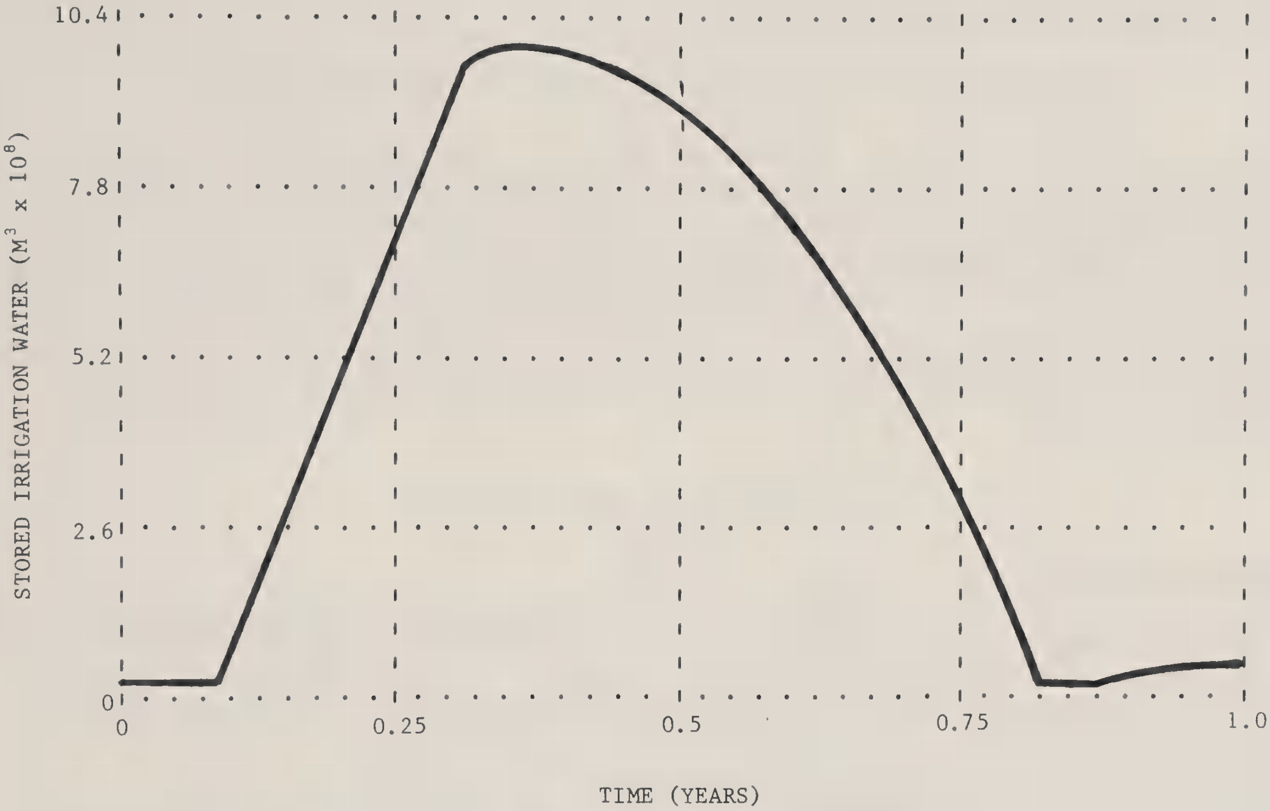
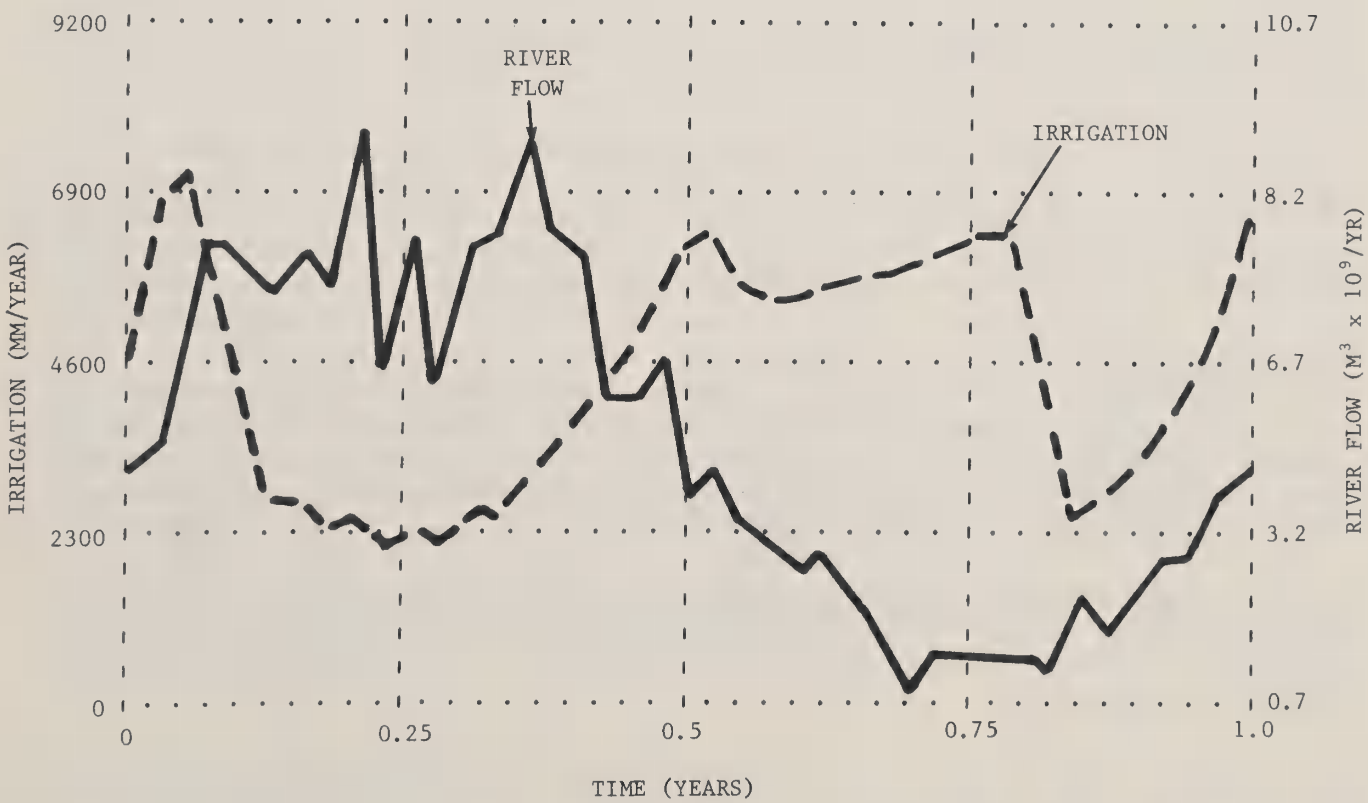


Figure 20. Model Simulation of the River Flow and Irrigation Use Over a 1-Year Period



sinusoidal, there being less need for irrigation during the wet season than during the dry season. The dip in irrigation during the last quarter of the year is due to the depletion of the reservoir. It is during this period of the year when crop damage may occur.

UNDERSTANDING THE SHORTCOMINGS OF IRRIGATION PROJECTS

The primary purpose of this report is to aid in improving the cost-effectiveness of irrigation projects in developing countries. In order to achieve this purpose, the analysis presented here provides an understanding of the factors that determine cost-effectiveness and explores policies to improve cost-effectiveness. The results of the analysis, which are presented in this section, compare and illustrate the behavior of a hypothetical irrigation project under various scenarios. In so doing, the magnitude of each policy's impact can be gauged to determine the most fruitful avenues for improving cost-effectiveness.

Description of the Scenarios

Business As Usual

In order to have some real-world system with which to compare, I have parameterized the model for Northeast Thailand. Certain variables such as the soil characteristics and rainfall pattern; income levels, interest rates, and prices; and farm size, consumption levels, and cultural attitudes were based on information from the northeast section of Thailand.

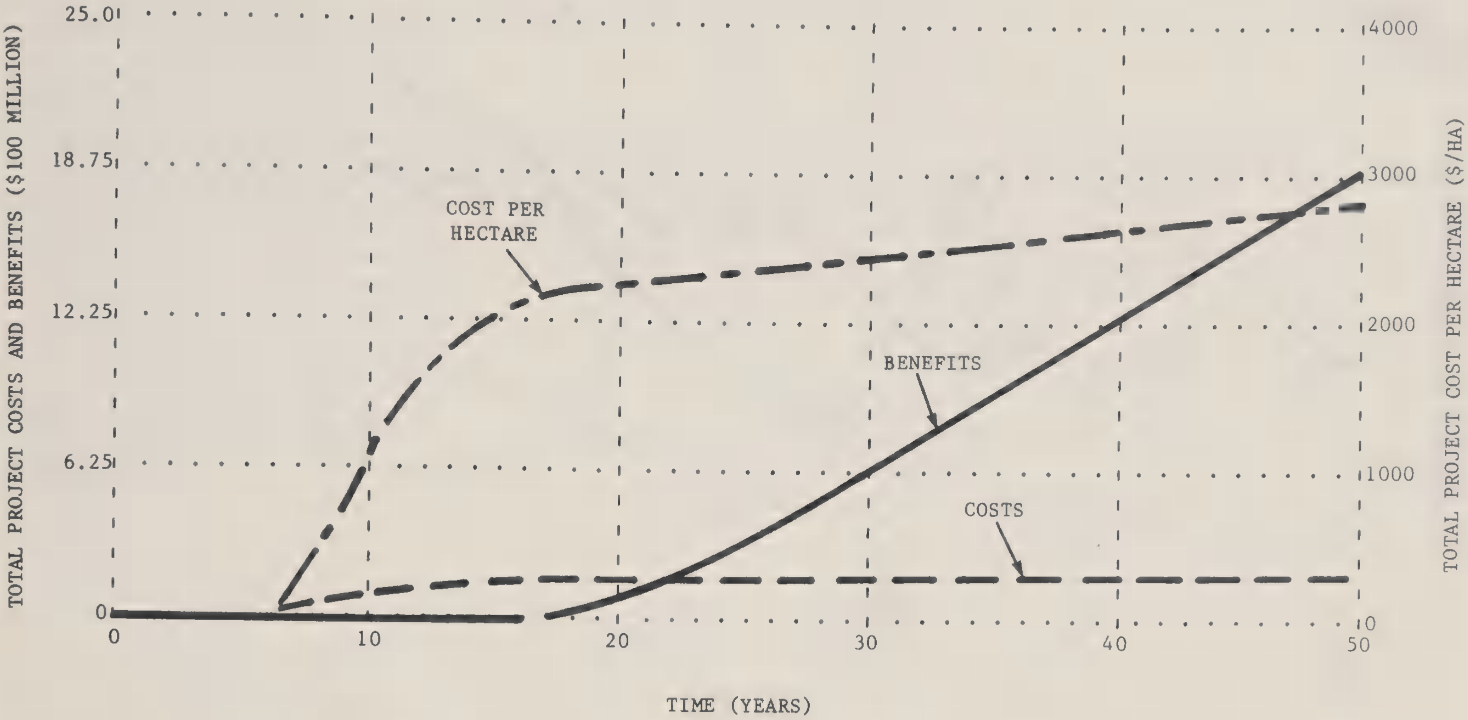
The model represents three phases or periods of an irrigation project: the pre-project period, the project design and implementation period, and the project operation period. During the pre-project period the irrigation project does not exist; the agricultural community of the project area continues to produce in a manner characterized by rainfed, subsistence agriculture. The first 5 years of the model simulations represent the pre-project phase.

During the next phase, project design and implementation, the project information is collected, the design quality is determined, and the project is constructed. In addition, the extension and credit programs are evaluated and enhanced during this period if they are to be included as project components. The length of the design and implementation period is variable depending on the time allowed for information collection and the rates of acceptable work completion, unacceptable work completion, rework, and acceptance of unacceptable work. The design and implementation period and the project operation period overlap for a few years as the system can deliver water when most of the project work has been completed. The project operation period then begins toward the end of the design and implementation period and lasts until the end of the simulation (50 years).

Two important measures of the success of an irrigation project are the costs and benefits of the project. Figure 21 shows the total accumulated project costs and benefits and the costs on a per-hectare basis (the project area is 75,000 hectares).

The costs accumulate rapidly during the design and implementation period but then slow as construction ends. The costs continue to increase slowly, as other expenses are involved in the maintenance and operation of the project.

Figure 21. Business-As-Usual Simulation of Total Project Benefits and Costs, and Project Costs Per Hectare

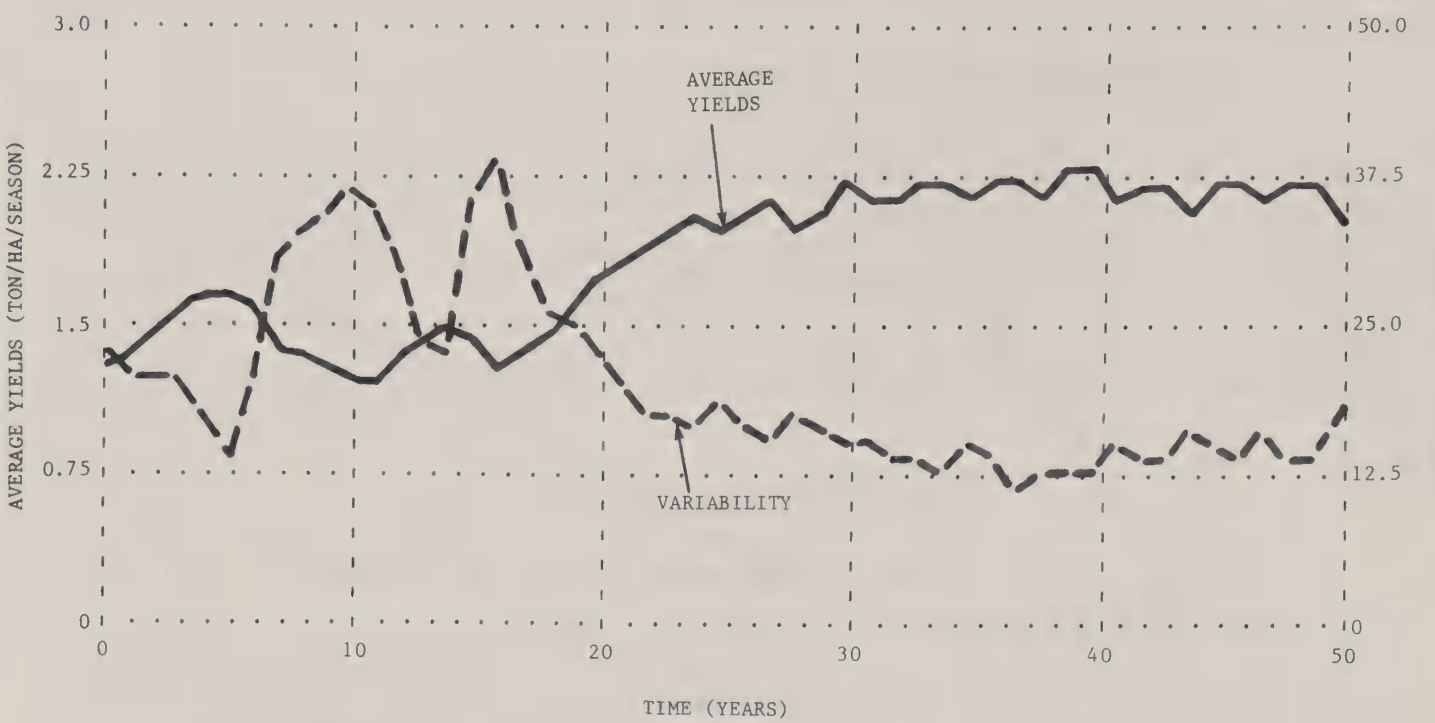


Costs include: construction costs, information collection costs, maintenance costs, extension and credit program costs, and fertilizer subsidy cost. The project benefits accrue from the value of the increased agricultural production and from the taxes on production. As Figure 21 shows, the benefits require a few years to accumulate enough to show up on the plot, but they grow steadily throughout the remainder of the simulation. To calculate the present value, I discounted the additions to total project benefits and costs for 35 years starting when the project began and summed the discounted benefits and costs. The present value was the difference between the sum of the discounted benefits and the sum of the discounted costs.

For the business-as-usual case the total costs reach $200 million, while the total benefits sum to almost $1.9 billion. The total cost per hectare approaches $3,000, of which the construction costs account for about $2,200 per hectare (compare with table 7).

While financial indicators are important they do not give a complete picture. Figure 22 shows the average yields and the variability in yields over the course of the simulation. As irrigation projects are aimed at improving these two variables, yields and variability give a measure of the project's performance. Figure 22 shows that the average yields do indeed increase after the project begins delivering water. Yields increase more than 50 percent, from around 1.4 tons per hectare per season to almost 2.25 tons per hectare per season. Limited acceptance of seed technology prohibits further increases in yields. Not shown here but also important is the number of seasons per

Figure 22. Business-As-Usual Simulation of Average Yields and Yield Variability



year. Prior to irrigation only one season is possible, but with the advent of irrigation the farmers can crop continuously and produce 2.4 crops per year.

Variability changes more dramatically than yields. Prior to the completion of the irrigation structures (year 16), the variability fluctuates according to the vagaries of nature. In some years, the monsoon provides adequate rainfall and yields are good, in other years the monsoon does not provide sufficient water and yields are poor. After irrigation is introduced, the yield levels become much more stable, and the variability falls from a high of about 38 percent yearly variation in yields to a low of about 12 percent. Towards the end of the run, variability begins to drift back up.

Figure 23 shows why this occurs. Yield levels and therefore yield variability depend upon adequate water deliveries. The ability of the system to deliver water in a timely fashion and in sufficient quantities depends in turn on the quality of the irrigation structures. As the average quality of the irrigation system deteriorates (figure 23) so too does the system performance. The system becomes leaky and the yields become more variable. In the business-as-usual simulation, the quality is adjusted relatively slowly during design and implementation period (years 6-16) but the quality diminishes rapidly during the project operation period because only minimum system maintenance is performed.

Social indicators must also be tracked in order to determine the effects of the project on the farming community. Figure 24 shows the average levels of savings and cash on hand and short-term debt for a typical farm family in the project area. The increased production resulting from the irrigation project has put the farm family in a better financial position. Savings and cash on hand increase significantly, and the family relies less on borrowing to

Figure 23. Business-As-Usual Simulation of the Average Quality of the Physical Structures

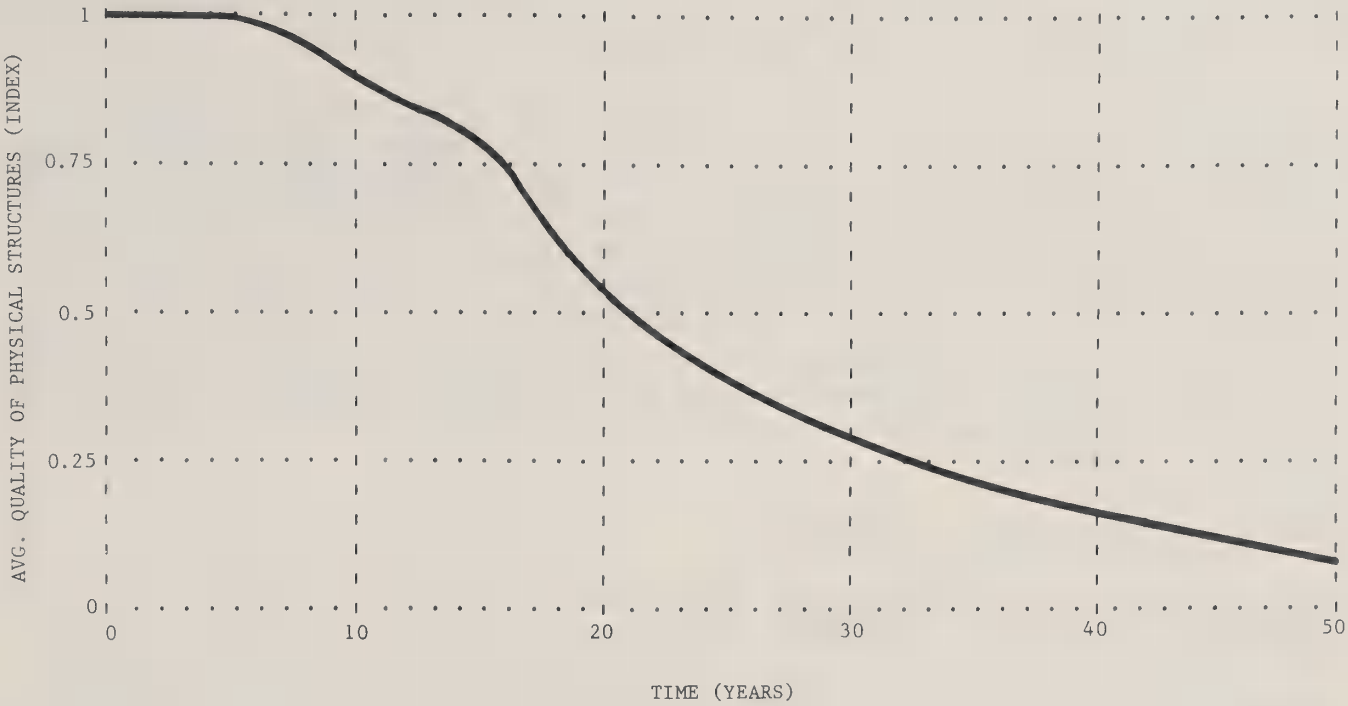
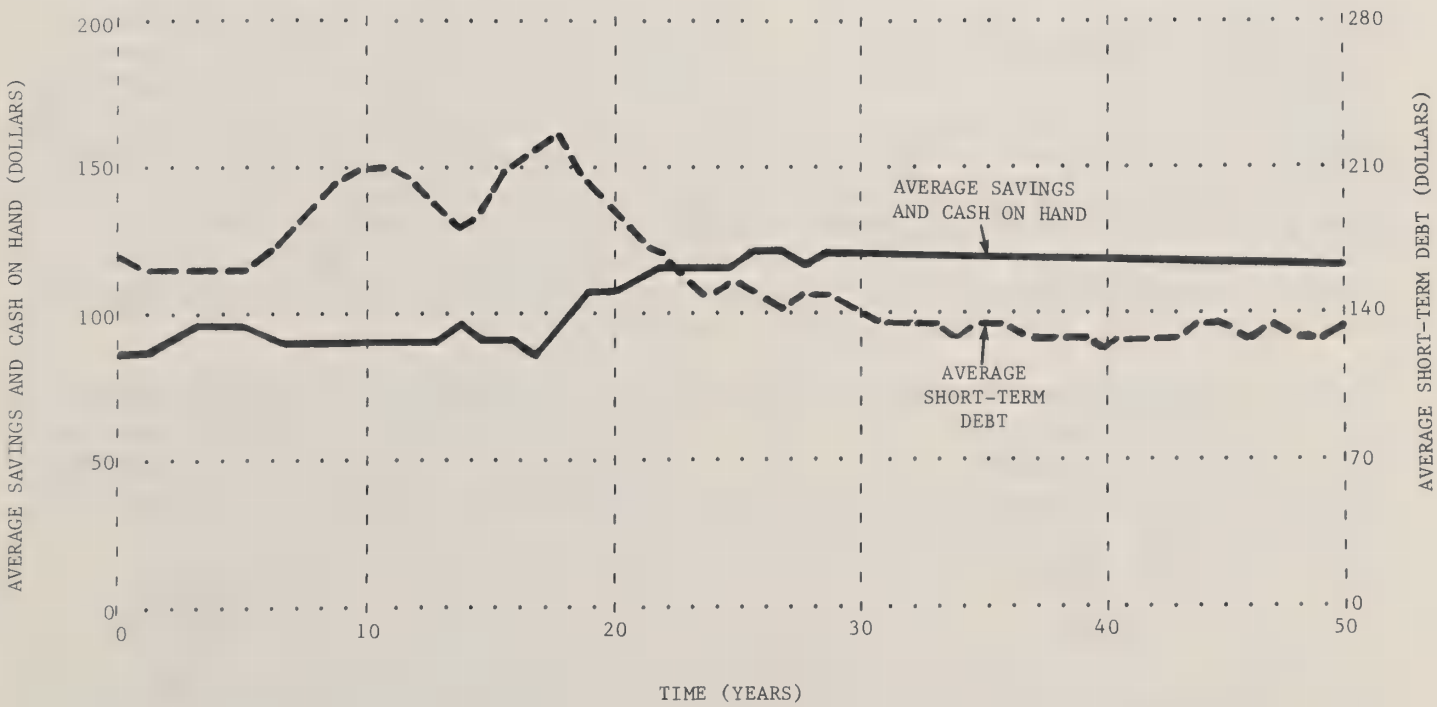


Figure 24. Business-As-Usual Simulation of the Yearly Averages of Savings and Cash on Hand and Short-Term Debt for A Typical Farm Family



sustain itself. In addition, the amount of family support (not shown) has increased in proportion to the level of savings and cash on hand. Before irrigation, the bulk of the harvest was used to provide for the family's own consumptive needs. With irrigation however, the family's consumption needs are met and there is a surplus that can be sold.

The increased sale of rice not only provides for greater family support and reduced borrowing, but also enables the farmer to invest more in fertilizer, further increasing yields (figure 25). During difficult times (years 7-13 and 15-18) fertilizer use falls off due to the combined influences of liquidity and risk. Poor harvests provide the farmer with less money to spend and a greater perception that the fertilizer investment is risky. Once again, the irrigation project improves this situation by increasing production and stabilizing yields. In addition, the extension program in effect here, while moderate, increases the farmer's level of experience, reducing the perception of risk and increasing the farmer's ability to apply the fertilizer in an efficient manner.

Improving the Design and Supervision

While the business-as-usual case illustrated a project that could be considered successful, relatively minor investments of time and money can significantly increase the returns. This series of policy tests is aimed specifically at the project design and implementation in order to improve the project's cost-effectiveness. The business-as-usual case allowed for only 1 year's time for information collection and moderate supervision of construction activities.

In the first test of this series, an extra year is allowed for information collection prior to construction. Table 8 shows that this simple policy increases the present value of the project dramatically.1/ The extra year of information collection provides for a better project design resulting in less rework (see figure 10) and lower initial costs, as figure 26 illustrates. In addition, the project design and implementation period is actually shortened by the addition of an extra year for information collection at the front end. Thus, the project benefits begin to accrue sooner due to the shorter construction period. A few very bad years are salvaged due to the early project implementation, so that the average yields show a dramatic change for this policy test, as illustrated in figure 27.

Similar results were obtained by improving the supervision of the information collection and construction processes. In the model, this result was achieved by increasing the political will of the government. A greater political will or political interest on the part of the government is one way to motivate supervisors to pay more attention to the tasks at hand, and thus more information is collected and less work needs to be redone.

Even more dramatic results were obtained when the extra year for information collection was combined with the increased supervision. Figures 28 and 29 show the simulations for this combination test. The costs are significantly reduced as almost no work needs to be redone, and the project is implemented in a very short time. In addition, yields are higher because the quality of

1/ It should be noted that constant returns to information collection efforts has been assumed.

Figure 25. Business-As-Usual Simulation of Fertilizer Use and Farmer Experience

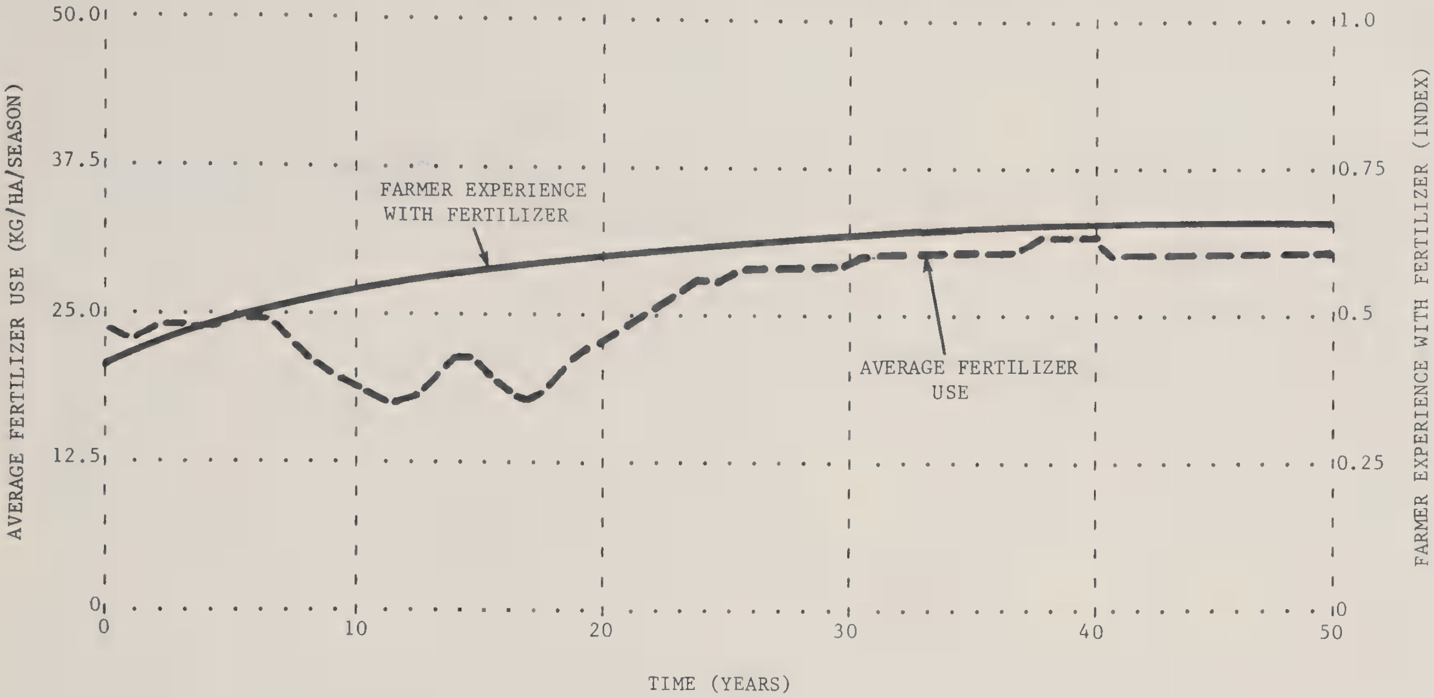


Figure 26. Simulation of Project Costs Per Hectare for the Base Case with and without an Extra Year of Information Collection

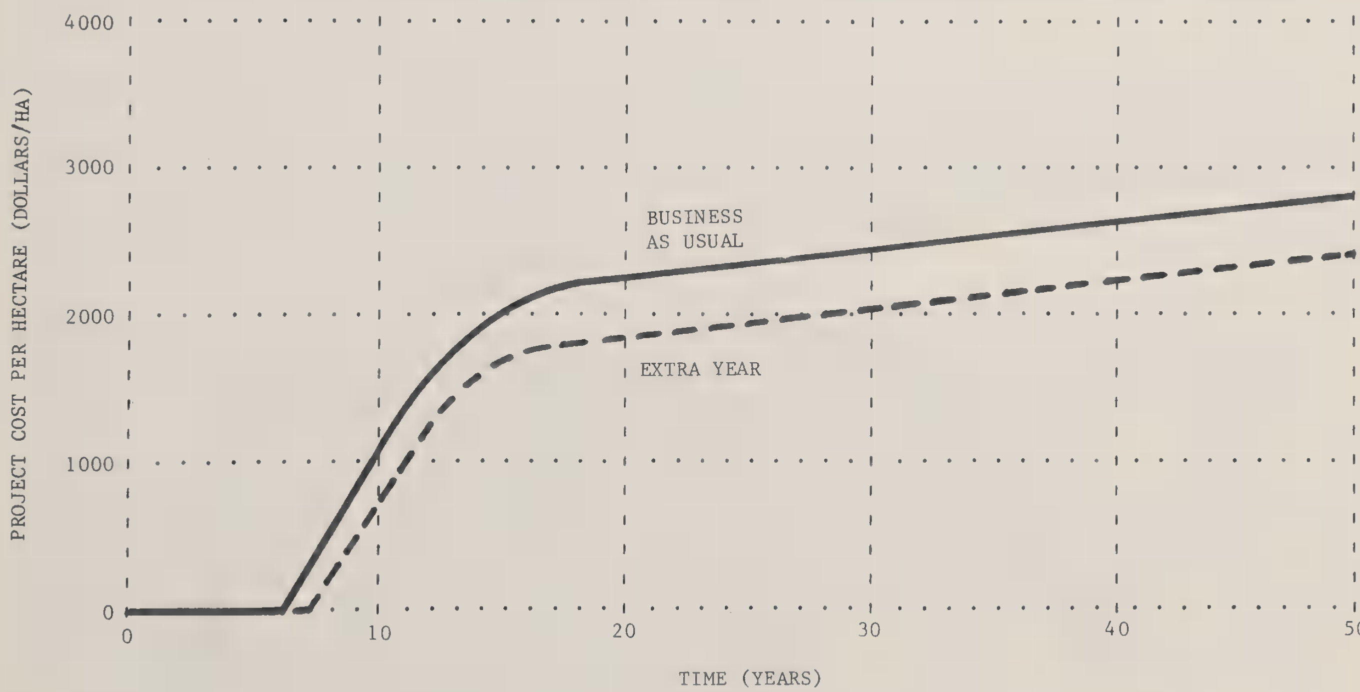


Figure 27. Simulation of Average Yield for the Base Case With and Without an Extra Year of Information Collection

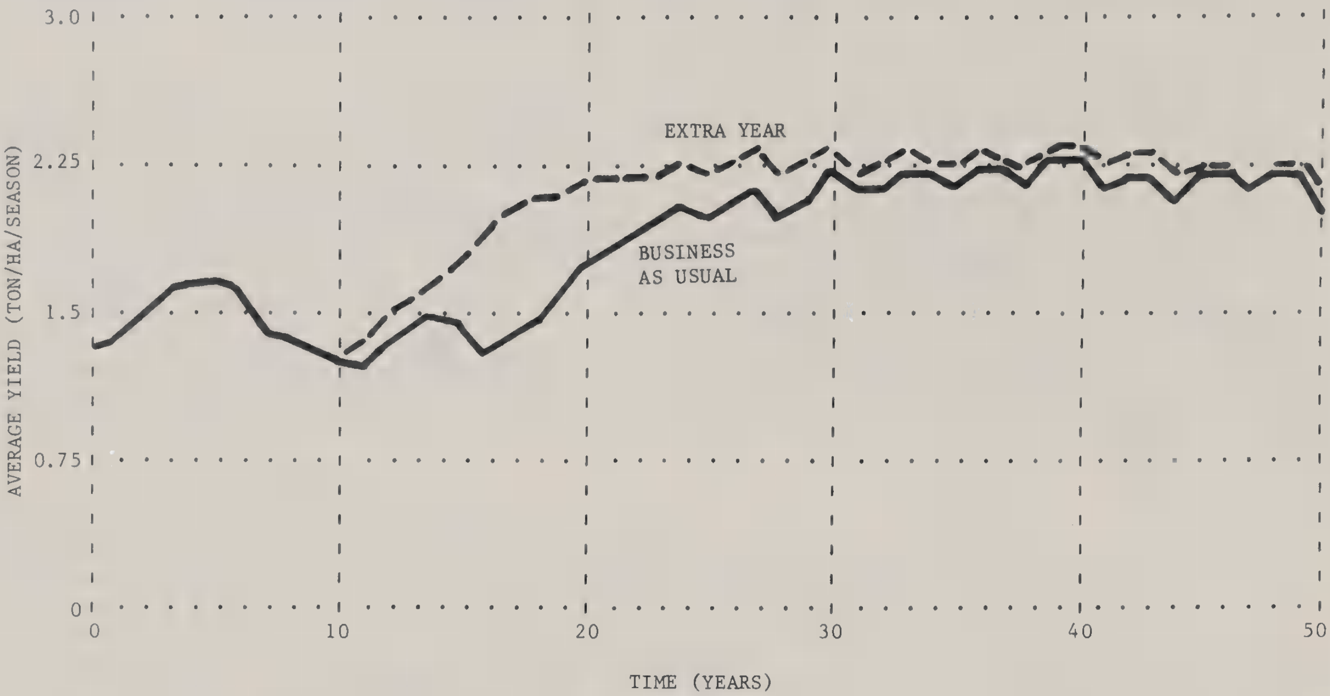


Figure 28. Simulation of Project Costs Per Hectare for the Base Case, and the Base Case With Extra Information Collection and Enhanced Supervision

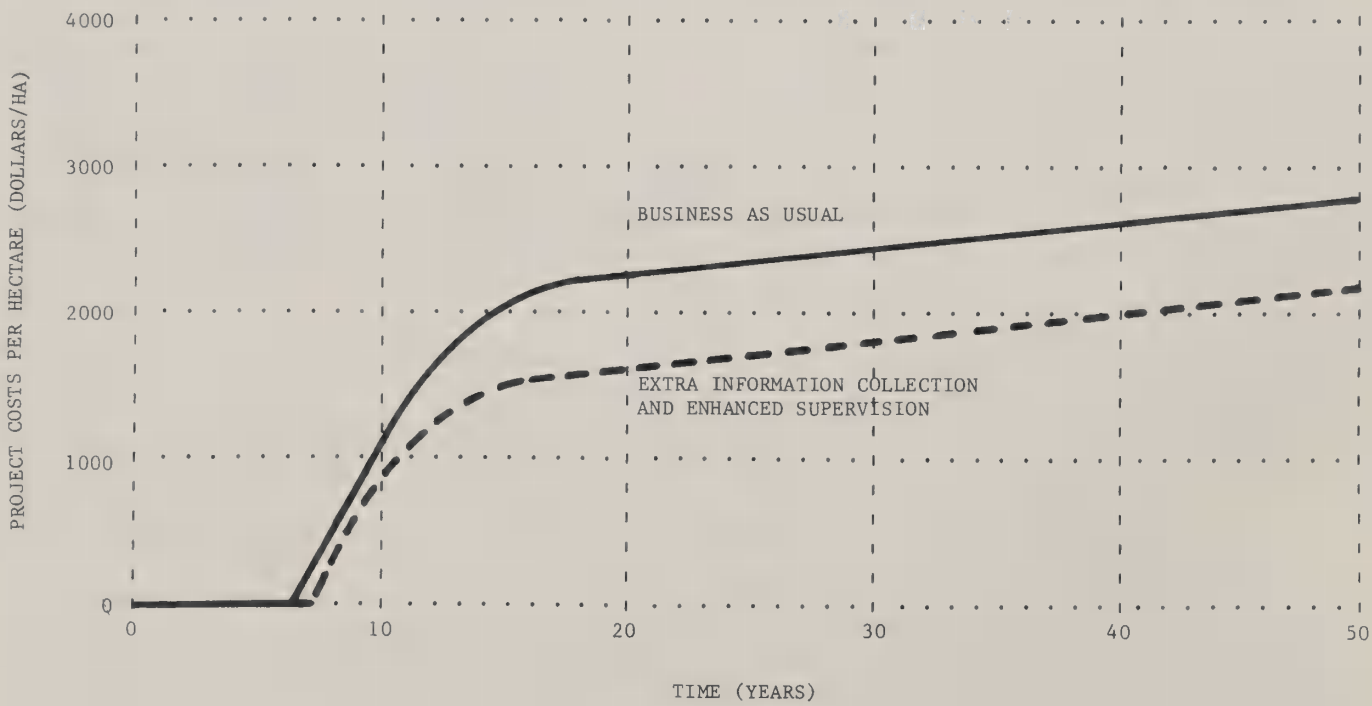
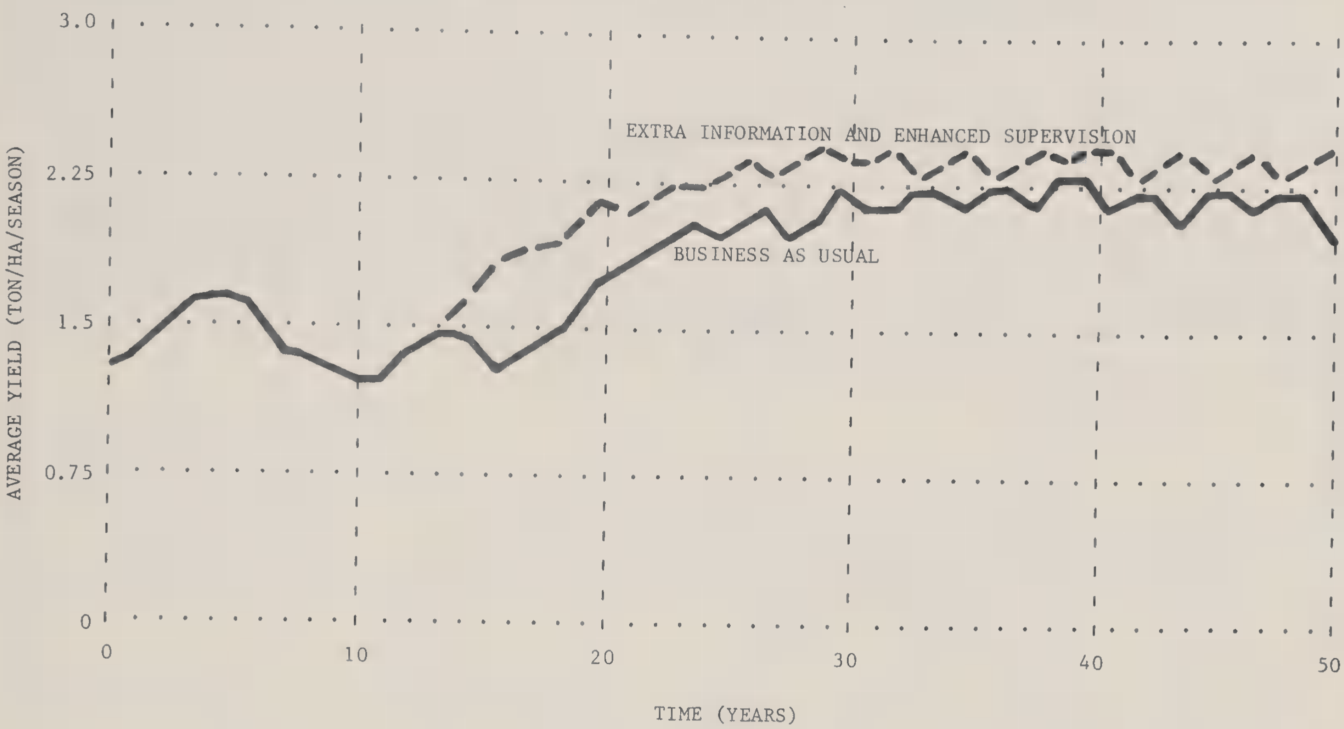


Figure 29. Simulation of Average Yield for the Base Case, and the Base Case with Extra Information Collection and Enhanced Supervision



the structures is greater and the extension program has been enhanced. This combination policy results in a project with a higher present value than either previous policy in isolation.

Maintenance Tests

Next to the actual cost of construction, the greatest project expense is for the system's maintenance. In this series of tests, I changed the rates of taxation for maintenance expenditures to see how varying maintenance levels can effect the system performance.

Figure 30 shows how low, normal and high maintenance levels corresponding to maximums of \$0, \$30 and \$60 per hectare per year change the costs of the project. Significant cost differences result at these maintenance levels. There are also significant differences in the variability of the yields from these low, normal, and high maintenance levels. Figure 31 tracks the variability for the three maintenance levels showing that the variability for the no-maintenance case is as much as twice that of the high maintenance case. More importantly, though, table 8 reveals that the optimal maintenance is somewhere between the no and high maintenance levels. The no-maintenance level allows too much deterioration, and yields are reduced to the point where the loss in benefits is greater than the savings in costs. The high maintenance level does not produce enough additional benefits to make up for the added expense. Instead, it appears that the most cost-effective maintenance level is one which allows the system to deteriorate but at a rate slow enough to extend minimum performance past a reasonable pay-back period. This view is confirmed by Barker:

Figure 30. Simulation of Project Costs Per Hectare for the Base Case with No Maintenance, Normal Maintenance and High Maintenance Levels

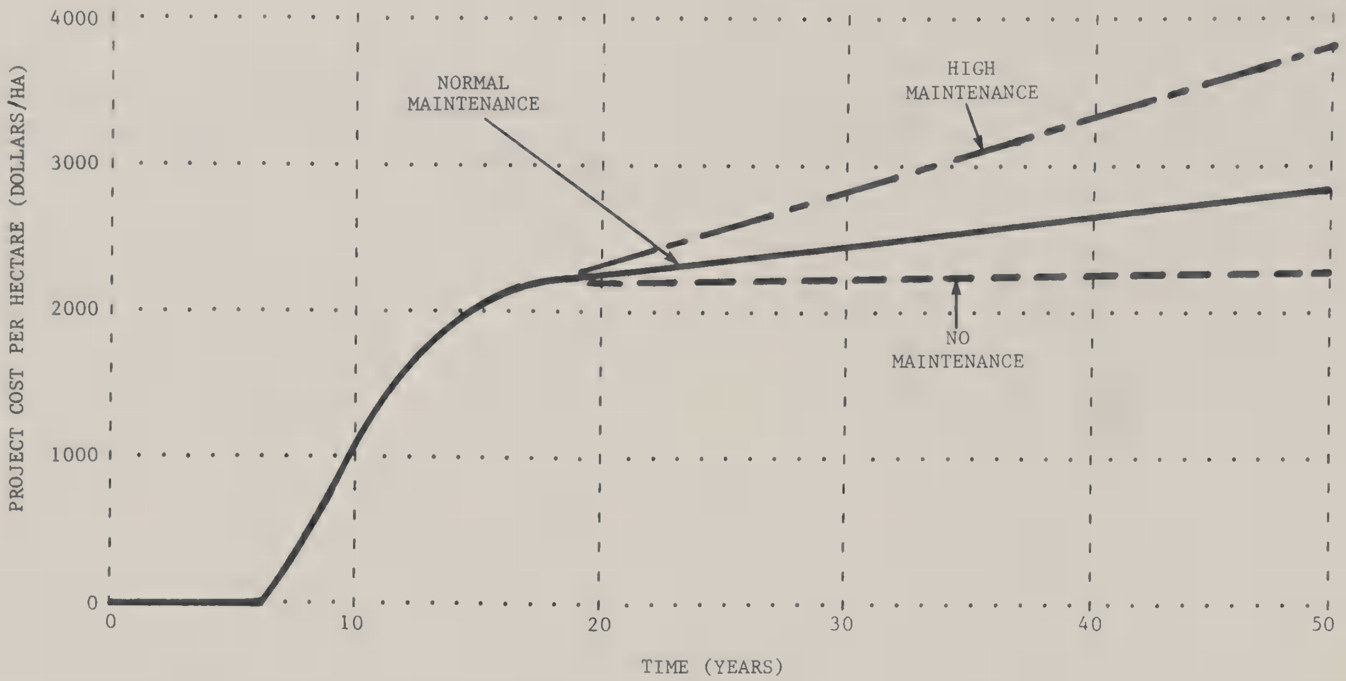


Figure 31. Simulation of Yield Variability for the Base Case with No Maintenance, Normal Maintenance and High Maintenance Levels

> ...from an economical perspective, this may be the most desirable way to handle the maintenance issue: that it is more economical to let the system deteriorate and be periodically rehabilitated than it is to try to keep it at top performance at all time (3).

One problem that this point of view overlooks and which I have not included in the model is the possibility of total system failure--that is, dam collapse. A primary objective in performing system maintenance is to maintain system performance, but another objective is to prevent the catastrophic failure of the reservoir. The poorer the system maintenance, the higher the probability of catastrophic failure. If this possibility were included in the present value calculations of table 8 the figures might look different; in particular, the estimate for the no-maintenance case would likely be much lower.

Removal of Extension Program

Although the system performance is an important determinant of a project's cost-effectiveness, the ability of the project's users to maximize project benefits is also an important factor. The farmer's knowledge and experience is of particular importance. Table 8 demonstrates that the neglect of this factor can cause project benefits to be reduced substantially.

Figure 32 illustrates the business-as-usual case with and without an extension program. Without the benefit of extension, farmers use less fertilizer and use it less effectively. The yields are significantly lower, and far fewer benefits accrue to the project. The cost of the extension program is relatively small, so only minor savings are realized.

Removal of Enforcement of Water Delivery Rules

Just as extension is important in determining project success, so to is the management of the system's water supply. Inefficient use of the water resources made available by the physical structures can significantly reduce the project benefits (table 8). The elimination of enforcement for water delivery rules dramatically reduces the present values of both hypothetical cases.

The water delivery rules limit the amount of water that each farmer can take. In the absence of enforcement of these rules it is in each farmer's best interest to take as much water as possible, while available, to ensure a successful crop. Water is wasted, and if the dam is emptied the system will be unable to provide water for anyone and low yields will result. Figure 33 shows the variability in yields for the business-as-usual case with and without enforcement. As the figure indicates, yield variability remains high when no enforcement is in place, even though reducing this variability and the risk associated with it is a primary objective of the irrigation project. Because farming remains a very risky venture, farmers are reluctant to invest in more fertilizer (figure 34) because there is a good chance that they will not realize a sufficient return on this investment. Poor water management and low fertilizer use combine to keep the project's benefits and present value low.

Figure 32. Simulation of Average Yield for the Base Case With and Without an Extension Program

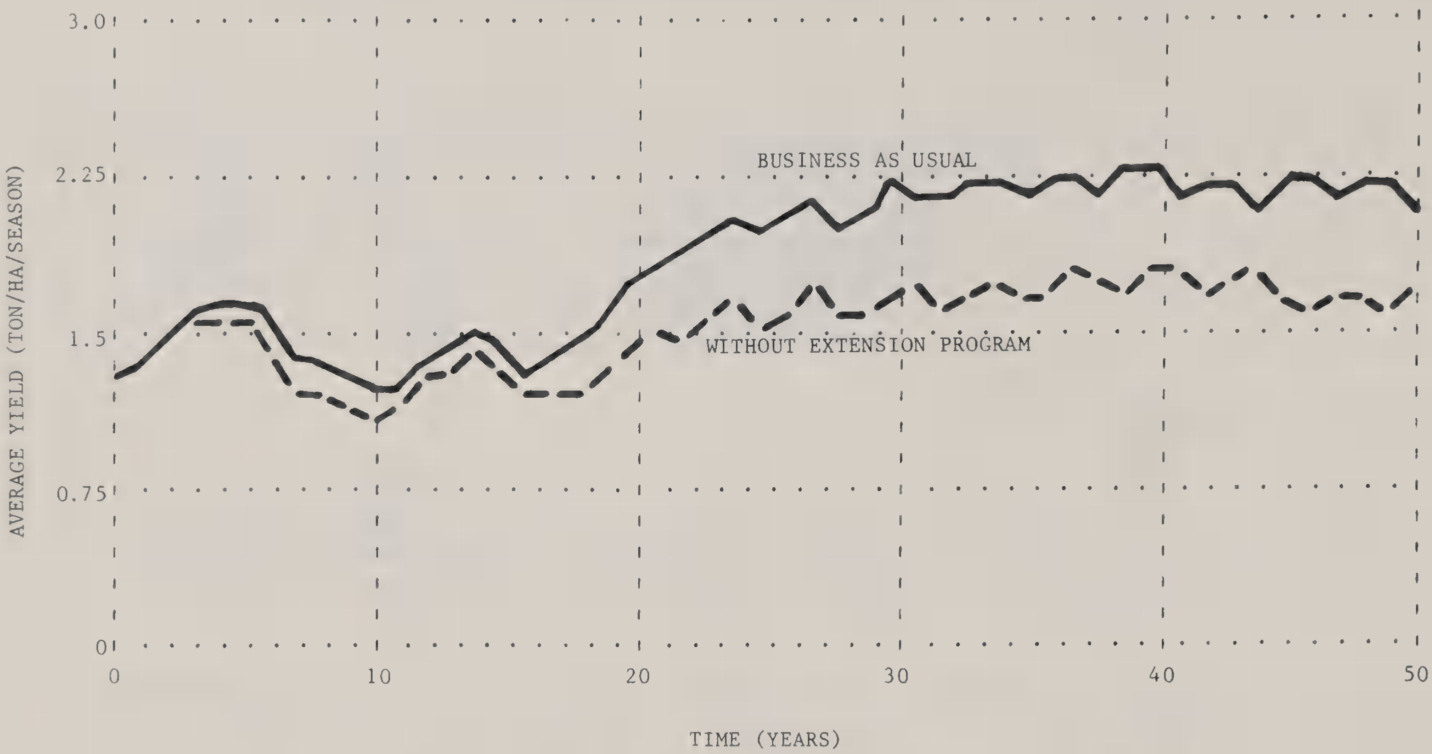


Figure 33. Simulation of Variability in Yields for the Base Case With and Without Enforcement of the Water Delivery Rules

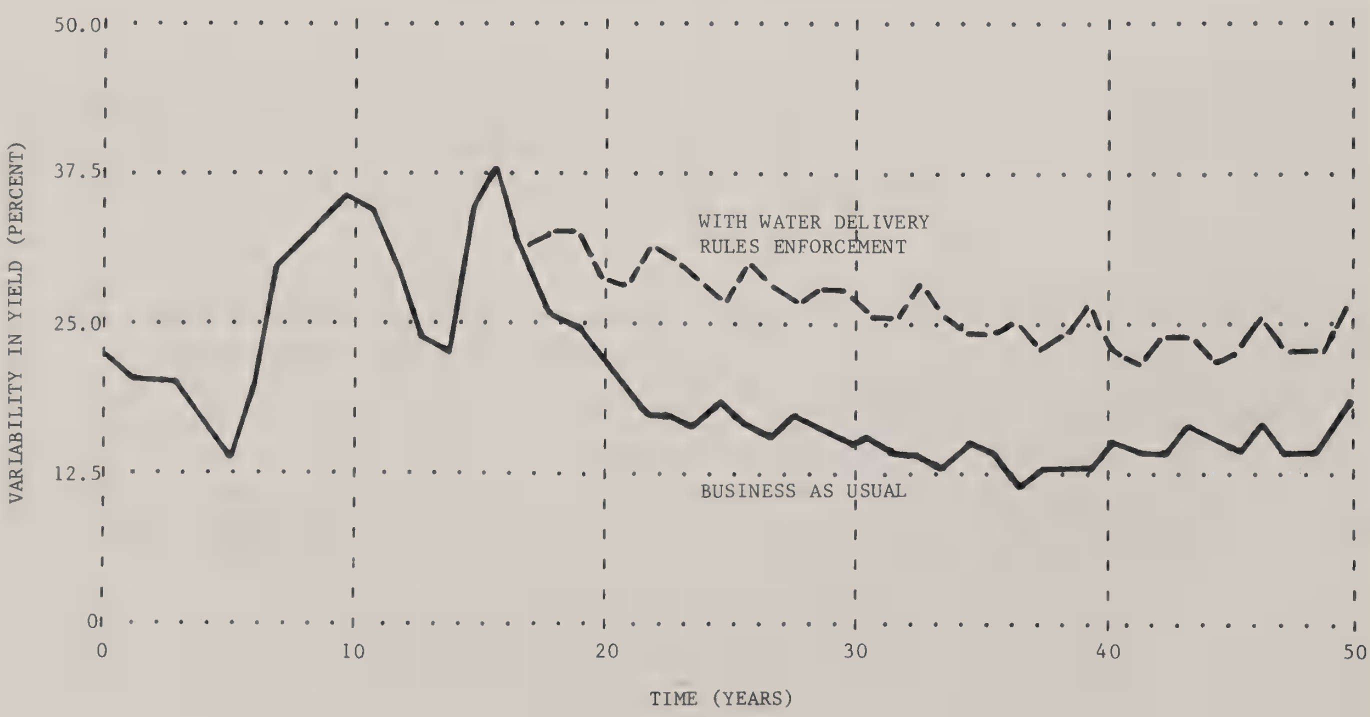
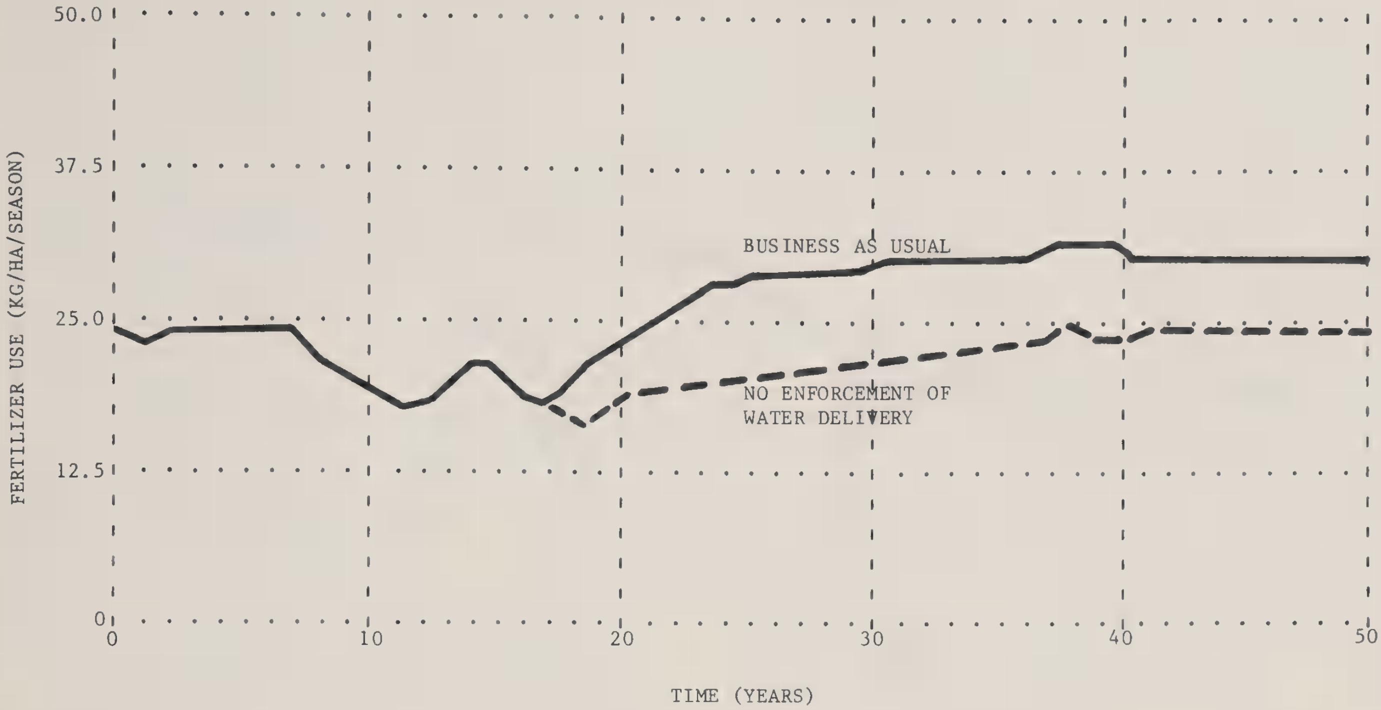


Figure 34. Simulation of Fertilizer Use for the Base Case With and Without Enforcement of Water Delivery Rules



Removal of the Credit Program

In some irrigation projects, credit programs are no doubt of major importance. The model runs in this series, however, show that for the hypothetical project, credit is not an important factor in determining project success. The removal of the credit program in fact improves the present values of both runs. The model shows that credit is much more important before the advent of irrigation than after. In figure 35, there is a significant reduction in yields before the project starts due to the poor financial situation of the farm family. With only one crop per year and no opportunity for borrowing, all expenses including fertilizer costs must be reduced. Figure 36 shows the difference in the levels of family support prior to irrigation with and without a credit program. Family support is significantly reduced during the growing season (time 0-0.425). Similarly, other expenses are decreased. After the project begins to irrigate the area, the additional rice production provides the family with a significantly increased income. With the savings and cash on hand thus enhanced, credit availability becomes less important in determining the family's expenditures. Figure 37 shows that the family support, a function of the savings and cash on hand, is much higher as a yearly average both with and without credit than before irrigation. Thus, the elimination of the credit program has not seriously reduced the farmer's purchasing power, and yield levels are only slightly different. The benefits are actually somewhat higher without the credit program as the pre-project yields are lower, and the credit expense is eliminated, resulting in higher benefits and lower costs. This explains the improvement in cost-effectiveness when the credit program is removed.

Figure 35. Simulation of Average Yield for the Base Case With and Without a Credit Program

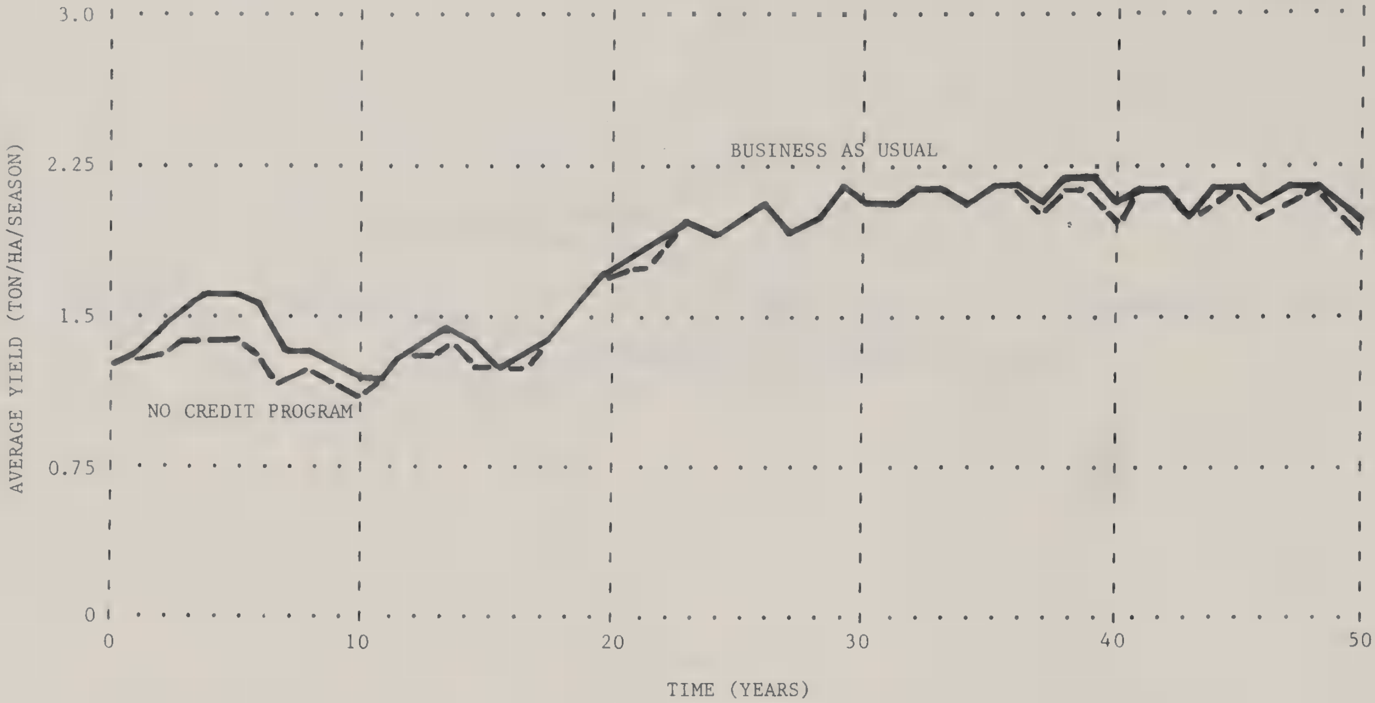


Figure 36. Simulation of Support Expenses for a Farm Family Over A 1-Year Period, With and Without a Credit Program, Prior to Irrigation

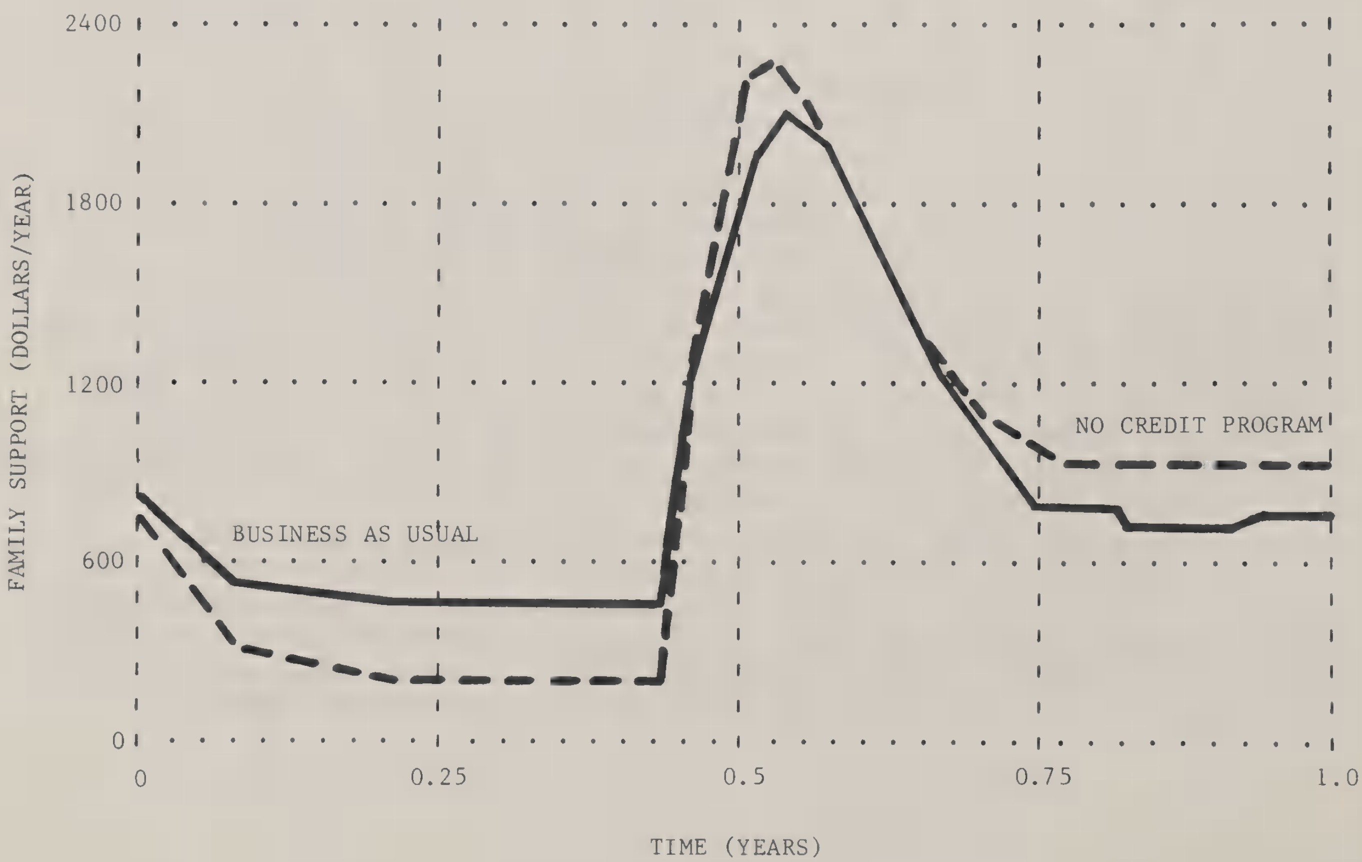
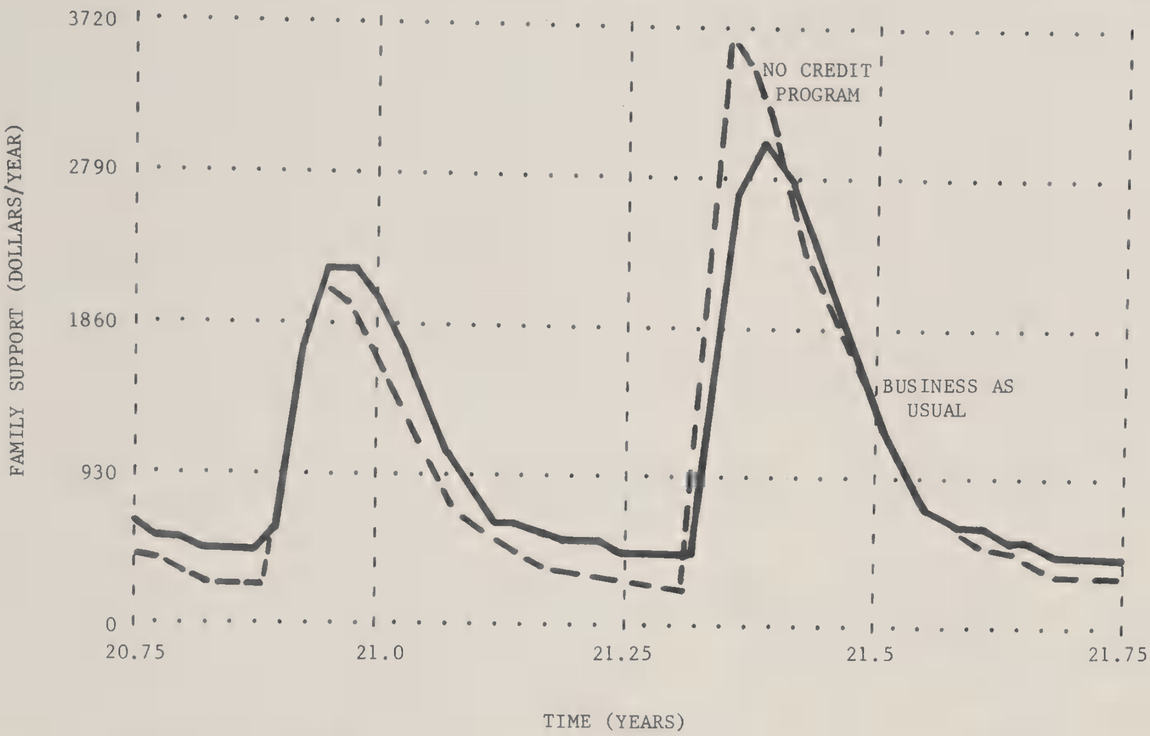


Figure 37. Simulation of Support Expenses for a Farm Family Over a 1-Year Period With and Without a Credit Program, After the Completion of the Irrigation



Note: Sales are different from Fig. 36.

Price Changes

The prices which a farmer receives and pays serve as incentives or disincentives to production. The more favorable these prices are to the farmer, the greater will be the desire to increase production, and the greater will be the ability to realize his desires. In this series of policy tests, the farmer's price structure was altered by lowering the tax on grain and increasing the fertilizer subsidy. Table 8 shows that changing these prices had a favorable effect on the project's success.

In the first test the $50-per-ton grain tax was eliminated. Although the grain tax is levied at the port of export, the tax is passed back to the farmer in the form of a lower producer price. Even though benefits are lost in the form of tax receipts, the increased production more than makes up for the tax losses. Similarly, a halving of the grain tax produces positive results.

While the reduced grain tax puts more money in farmers' pocket, giving them a more favorable return on investment, the fertilizer subsidy eases farmers' monetary constraint for fertilizer purchases. This allows the purchase of fertilizer for the same cost. In this policy test, the subsidy is increased from $14 to $100 per ton to lower the effective fertilizer cost to $450 per ton from $536 per ton. This entails some loss to the government, but the incremental increase in production more than makes up for the added costs.

Table 8--Normalized present values of a hypothetical irrigation project under different scenarios

Simulation description	Normalized present value 1/	
	Without extra information collection	With extra information collection
Business as usual	1.0	4.2
Enhanced supervision	4.4	6.7
No system maintenance	.76	4.0
High system maintenance	.84	4.2
No extension	-.32	2.3
No enforcement of water delivery rule	-1.0	1.6
No credit program	1.2	4.9
Grain tax removed	1.4	5.1
Grain tax halved ($25 per ton)	1.1	4.7
Fertilizer cost Subsidized ($100/ton)	1.3	4.7

1/ The present values were calculated using a 10-percent discount factor and a 35-year payback period.

A Comparison of the Policy Tests

In order to provide a simple summary of the policy tests performed with the model, I have calculated the present value of each hypothetical project for each policy test and normalized the estimates against the business-as-usual case. These present value calculations are presented in Table 8. The numbers presented are intended to provide a measure of the effectiveness of each policy test on a hypothetical irrigation project. The numbers themselves are only important so far as they relate the success of one policy to another. The numerical differences between policy tests are not important, but the fact that a certain policy increased or decreased the present value, and that the change was large or small is very important.

Table 8 contains a separate column which has been provided for the scenario in which an extra year of information collection has been allowed. This is because of the great differences which this policy makes. The inclusion of this column also demonstrates more dramatically the effects of certain policies on the success of a project.

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